JUNE, 1950

JOURNAL OF THE IRON AND STEEL INSTITUTE

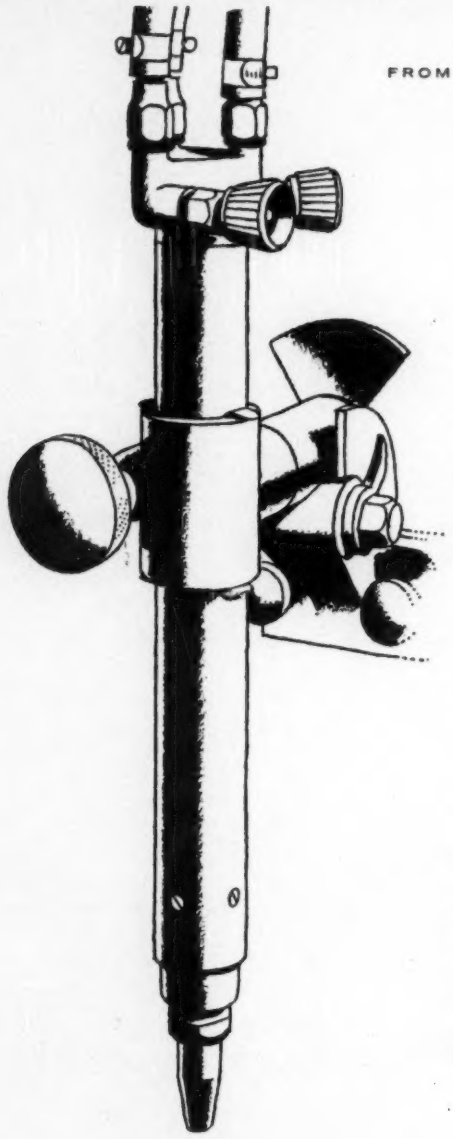
4 GROSVENOR GARDENS, LONDON, S.W.1

Established 1869 Incorporated by Royal Charter 1899

Principal Contents

PRICE ONE POUND

FROM BRITISH OXYGEN – FOR BRITISH INDUSTRY



The best

oxygen cutting machines

in the world

Bantam. Portable (22 lb) robust, versatile, for straight line and circle cutting (straight edge or bevel). Also cuts simple profiles. The mechanised cutter for every engineering shop.

Beagle. Transportable (125 lb) profiling machine . . . for one-off work tracing direct from drawing, eliminating need for templates; unique head for bevel cutting on any profile.

Bison. A precision machine tool for high quality profiling from steel or wooden templates, or direct from drawings. Takes up to three heads for multiple cutting.

36″ Universal Cutting Machine. Highly popular general purpose profiling machine for busy work-shops.

55″ Universal Cutting Machine. Robust machine for precision cutting of heavy steel up to 24″ thick.

Oxyplane. Specially designed for flame planing of large plates to the close tolerances required for automatic welding. Four sides planed simultaneously to any required preparation.

Think what a new British Oxygen Cutting Machine of the latest design can mean to you in increased output and higher quality precision cutting Write for fully illustrated literature.

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British Oxygen Gases Ltd., Industrial Division, Spencer House, 27 St. James's Place, London, S.W.1.

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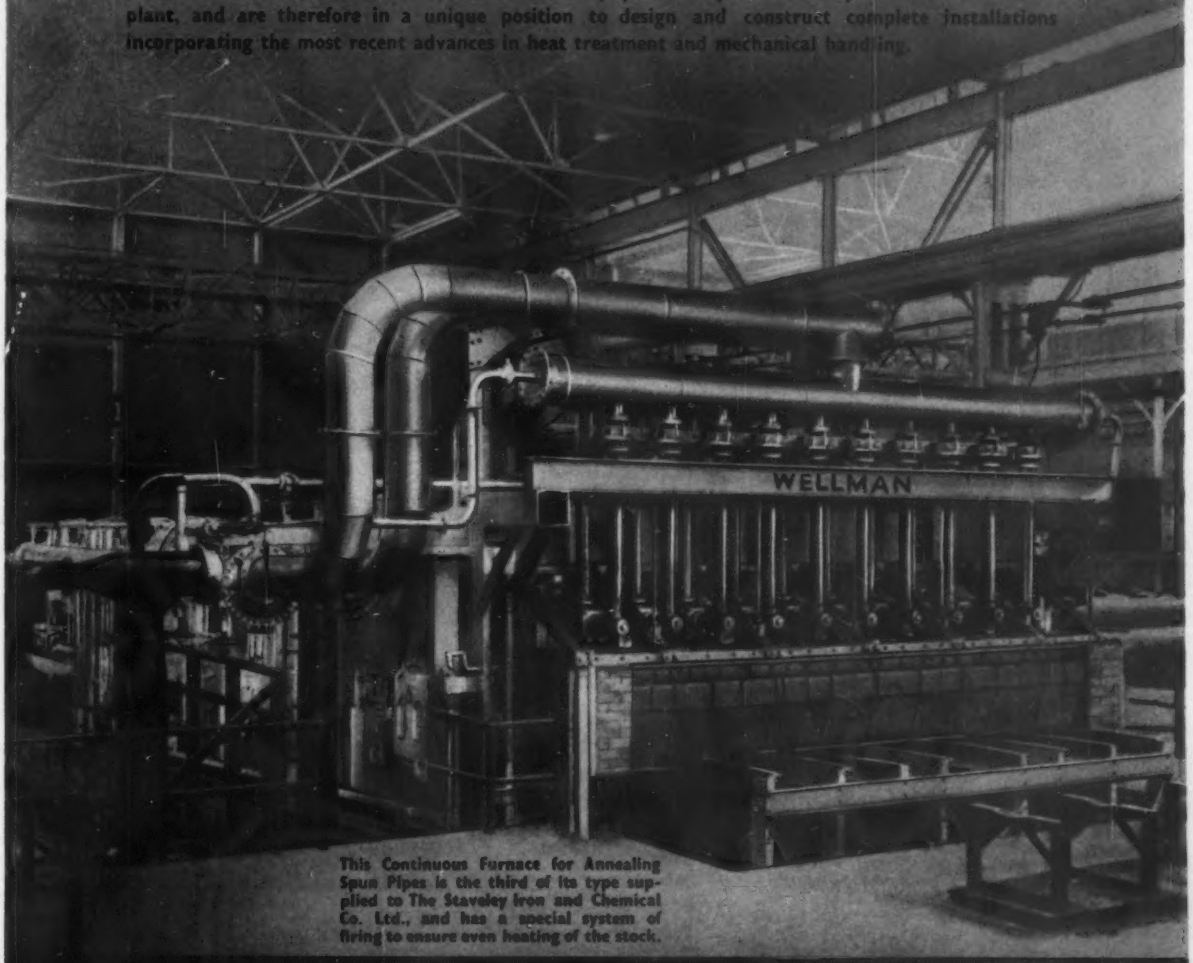
Re-Heating and Heat Treatment Furnaces for the Metallurgical Industries

We design and construct Re-Heating and Heat Treatment Furnaces of many types for both ferrous and non-ferrous trades ranging from small units dealing with castings of a few pounds each up to the largest Bogie Heat Treatment Furnaces handling single pieces of 100-tons and upwards.

With the increased demands for precision and for constant quality, automatic control of furnace conditions is recognised as essential and this subject has received special attention in our engineering and research departments where every aspect of heating technology is studied.

We are also makers of the mechanical equipment required in conjunction with furnace plant, and are therefore in a unique position to design and construct complete installations incorporating the most recent advances in heat treatment and mechanical handling.



This Continuous Furnace for Annealing Spun Pipes is the third of its type supplied to The Staveley Iron and Chemical Co. Ltd., and has a special system of firing to ensure even heating of the stock.

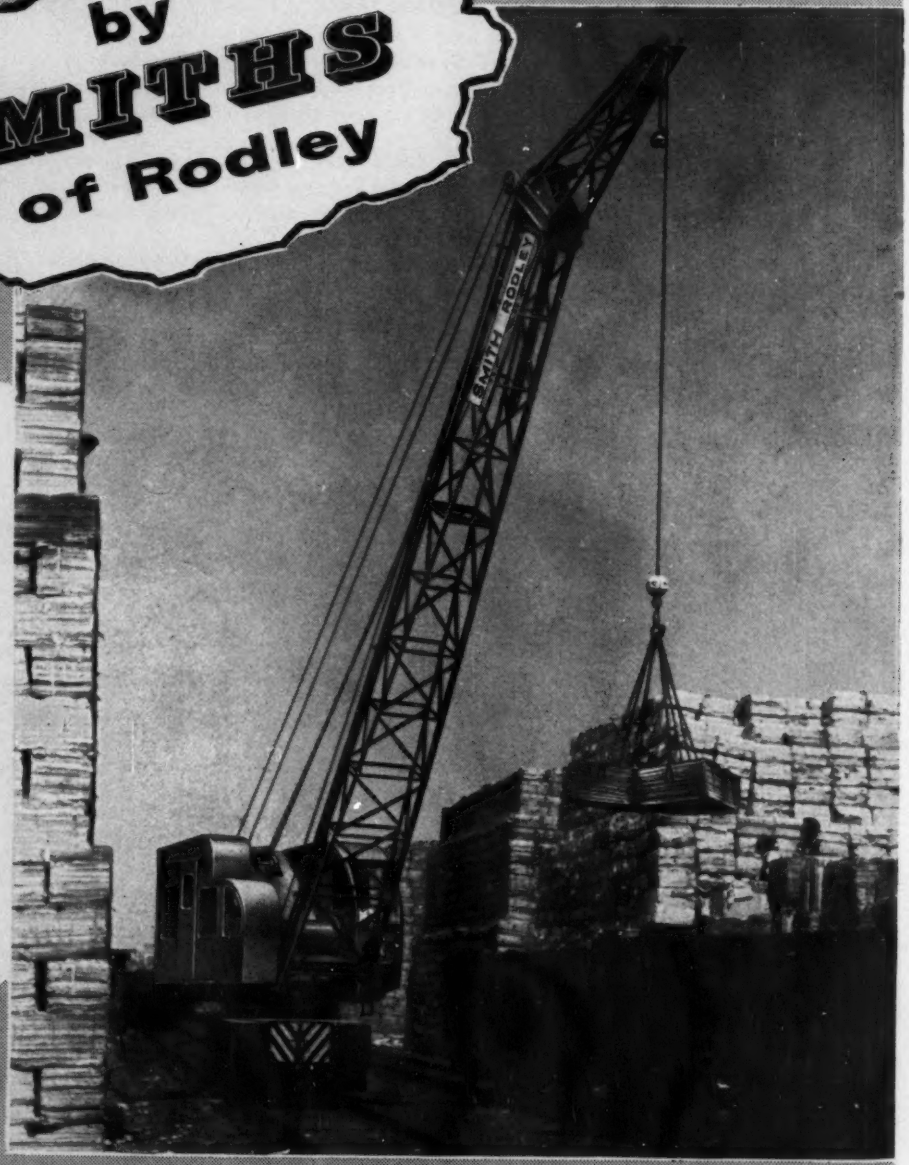
THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LTD.

PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, South Staffs, & BELFAST.

Serving Industry everywhere!

DIESEL CRANES

by SMITHS of Rodley



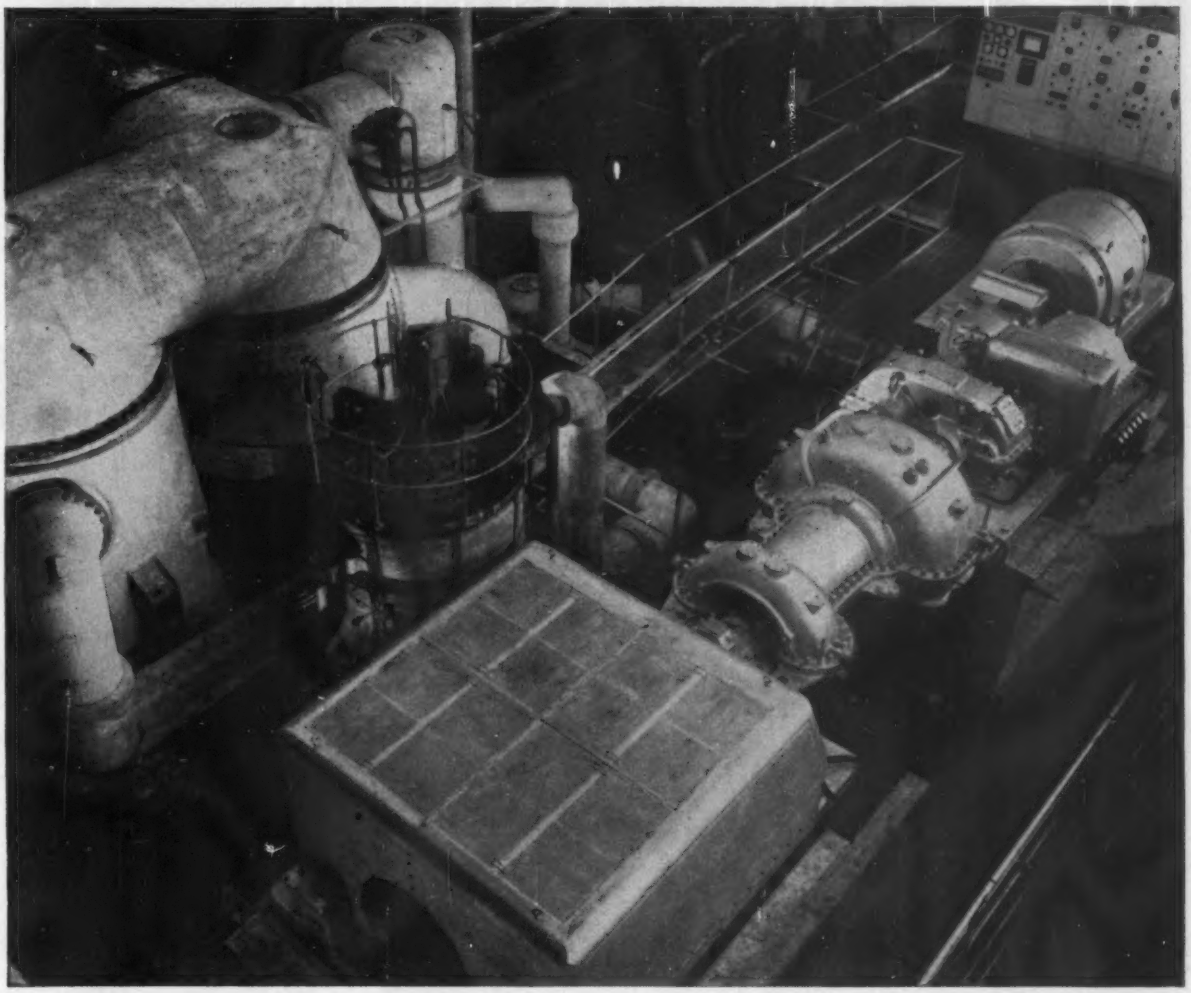
Smith Diesel and Diesel-Electric locomotive and shunting cranes serve many industries, particularly engineering and steelworks, docks and railways, stockyards, etc. Photograph at right shows a Smith 3-ton Diesel shunting crane engaged on stacking duties at a large paper mill in Lincolnshire. Using a 50 ft. cranked jib, it lifts 3 tons at 22 ft. radius. The very fast hoisting speed (200 f.p.m.) is ideal for this class of work.

THOMAS SMITH & SONS (RODLEY) LTD

Crane and Excavator Works · Rodley · Leeds · England

2,500 kW Gas Turbo-Alternator on Test at Hartlepool

This open-cycle gas turbo-alternator for Shelton Iron & Steel Ltd. is designed to burn blast-furnace gas, gas-oil or a mixture of the two. The guaranteed overall thermal efficiency (output measured at the alternator terminals) is 20.5 per cent.



It was built at the works of . .

Richardsons Westgarth (Hartlepool) Ltd.

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who are able to build gas turbines up to 30,000 kW per unit.
They are also manufacturers of land and marine steam turbines,
water tube and shell boilers, turbo blowers and gas
exhausters, condensers, feed heaters and water strainers.

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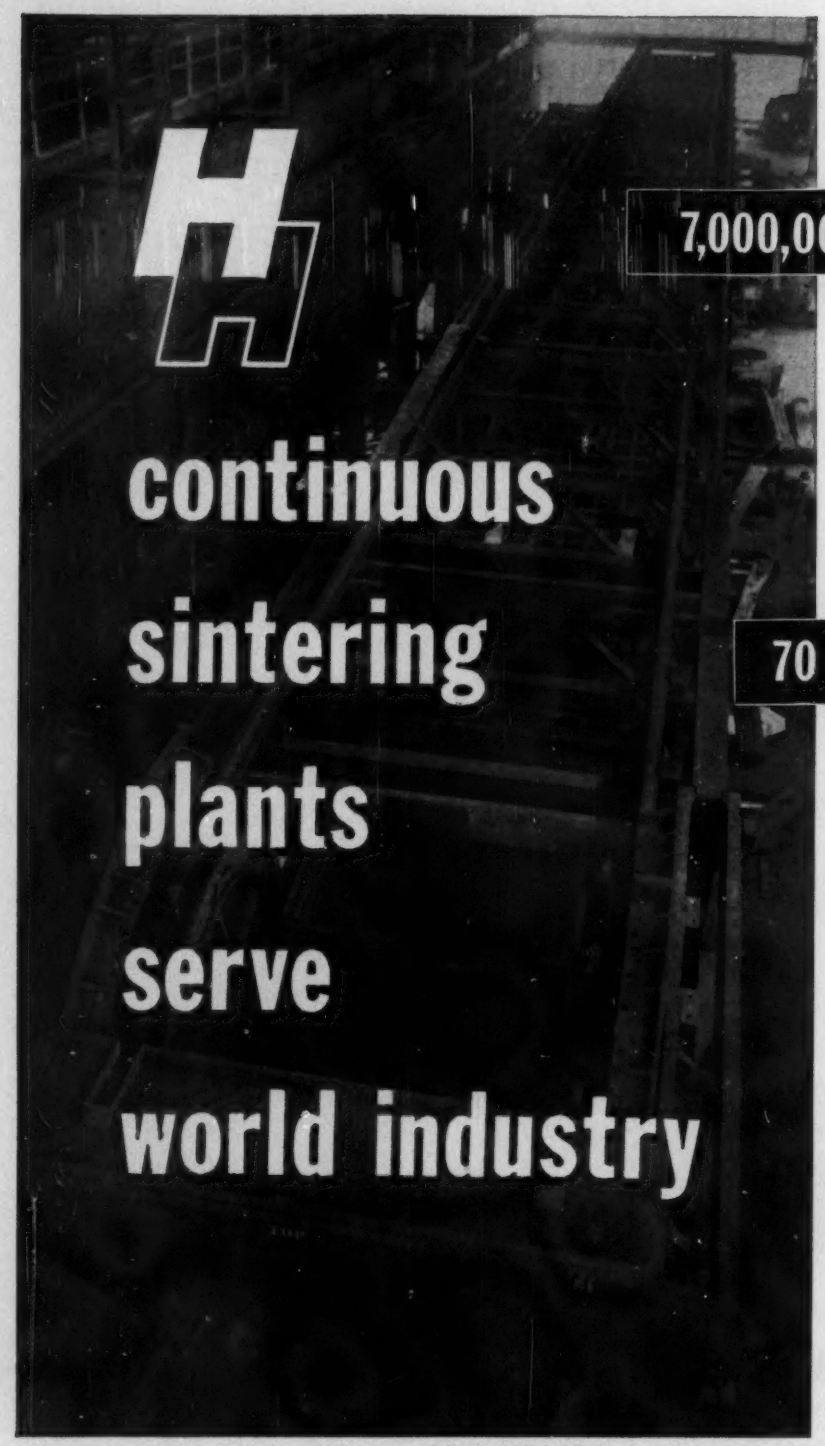

continuous sintering plants serve world industry

7,000,000 tons per year

Seven million tons of sinter per annum is the impressive aggregate output of the fifteen sinter plants ordered by iron and steelworks at home and abroad from Huntington Heberlein since the beginning of 1955.

70 years' experience

Behind the design of these plants, in Britain, France, Belgium and South Africa, is some seventy years' experience of the sintering process which is coupled with an up-to-date knowledge of the latest techniques and potentialities of the process.

ASSOCIATED IN THE U.S.A. WITH KOPPERS COMPANY INCORPORATED.

Other specialities include:

Ore Dressing Plants, High Intensity Magnetic Separators, Herreshoff Furnaces, Badische Turbulent Layer Roasters, Contact Sulphuric Acid Plant, Mechanical Saltcake Furnaces and Hydrochloric Acid Plants.

A Huntington Heberlein sintering plant under construction

Continuous sintering plants by

Huntington, Heberlein & Co. Ltd

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SIMON HOUSE, 28-29 DOVER STREET, LONDON, W.1. Telephone: Hyde Park 8191. Telex: 2-3165. Telegrams: Innovation Wesphone London Telex

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HH22

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make installation

easier

quicker

and cheaper

TRI-MOR GRADES

TRI-MOR Standard Castable
A medium texture refractory having negligible shrinkage up to 1,350°C. Suitable for casting special shapes or for monolithic structures. Limiting service temperature 1,350°C.

TRI-MOR High Strength Castable
A similar refractory to Tri-Mor Standard Castable, but specially developed to have very high mechanical strength over the lower temperature range. Maximum service temperature 1,250°C.

TRI-MOR High Temperature Castable
Suitable for face temperatures up to 1,600°C; has an extremely high resistance to thermal shock; used for cast in situ monolithic structures and for pre-cast refractory shapes; can be applied with a cement gun.

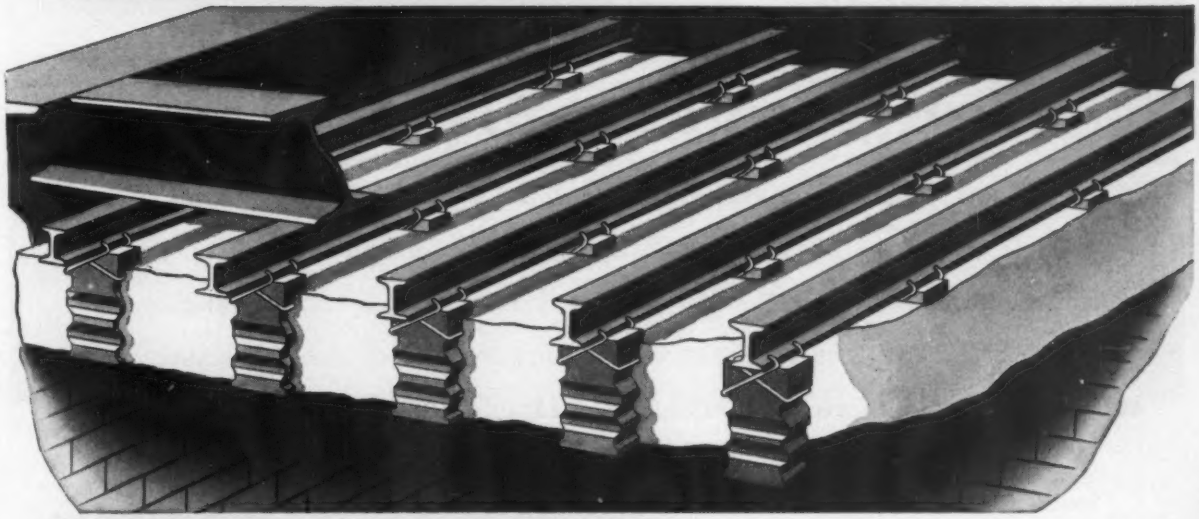
TRI-MOR High Temperature Mouldable
A plastic refractory for use up to 1,650°C: low shrinkage and a high resistance to spalling. Supplied mixed to the correct consistency for installation.

TRI-MOR Dense "Guncrete"
A hydraulic setting refractory with a maximum service temperature of 1,300°C. It has a high resistance to abrasion. Designed for application by cement gun, but can be trowelled.

TRI-MOR Insulating Castable
An insulating castable for maximum service temperatures of 1,200°C; low thermal conductivity is its main feature.

TRI-MOR Insulating "Guncrete"
Similar to Tri-Mor Insulating Castable but for application by cement gun.

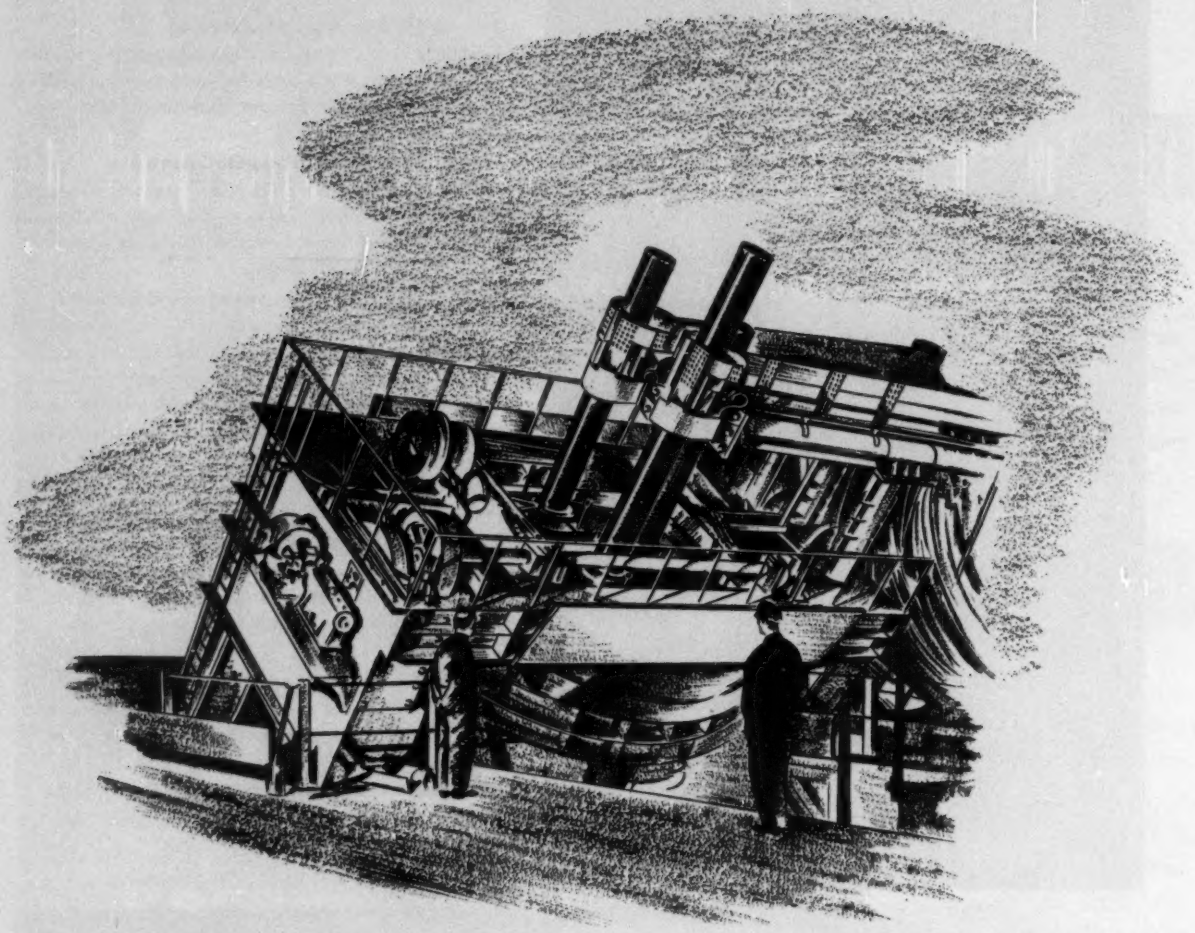
Full details of each grade are available on request.



Soaking pit cover in Tri-mor High Temperature Castable with ceramic keys.

MORGAN Refractories Ltd

For further information please write to: MORGAN REFRACTORIES LTD. NESTON, WIRRAL, CHESHIRE. TEL: NESTON 1406 NE 136



Arc Furnace Electrodes

When Dr. E. G. Acheson discovered the secret to the production of artificial graphite he opened the way for a tremendous growth in the use of electric arc furnaces for steel melting. Today the arc furnace proudly ranks as a major producer of steel for British Industry, and large or small there are "Acheson" Graphite Electrodes for every furnace. There is none better.

ACHESON TRADE MARK GRAPHITE

The term ACHESON *is a trade mark*

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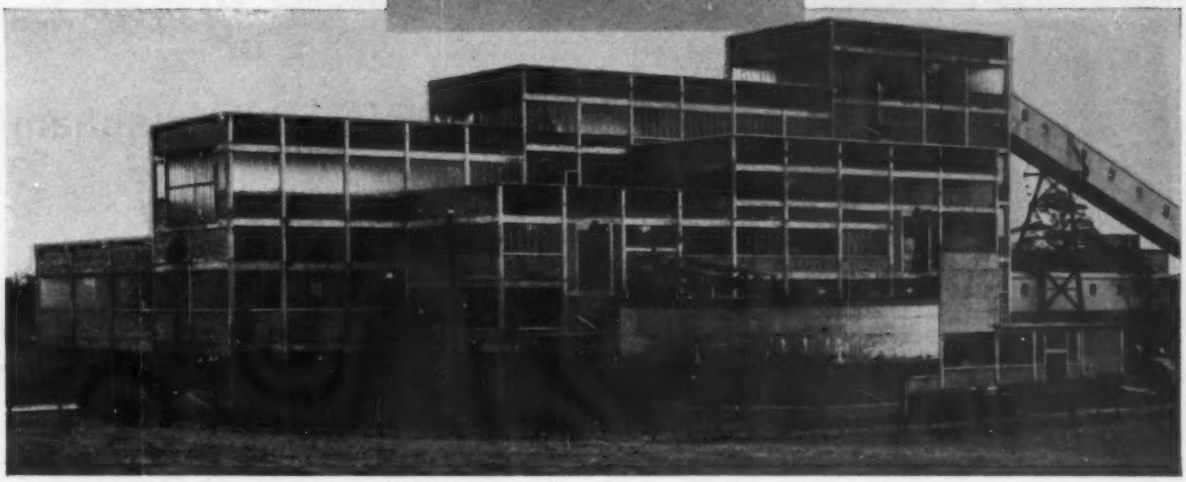
COPPEE 1ST.

FIRST TO CONSTRUCT SCOTLAND'S CENTRAL COAL PREPARATION PLANT (at Dalkeith)

AND FIRST TO CONSTRUCT SCOTLAND'S HEAVY MEDIUM COAL PREPARATION PLANT (at Barony)



Scotland's new heavy medium coal preparation plant at Barony Colliery was designed and constructed throughout by The Coppee Company — Britain's leading constructional contractors to the coal industry.

This plant which cleans coal for domestic use up to a rate of 450 tons per hour also supplies fines for fuel used at the Barony Power Station.

THE COPPEE COMPANY (GREAT BRITAIN) LIMITED

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this
tippler
feeds
over
3 million
tons
of iron ore
to 7¼ miles of belt conveyors
at the Seraphim plant of
the Appleby-Frodingham
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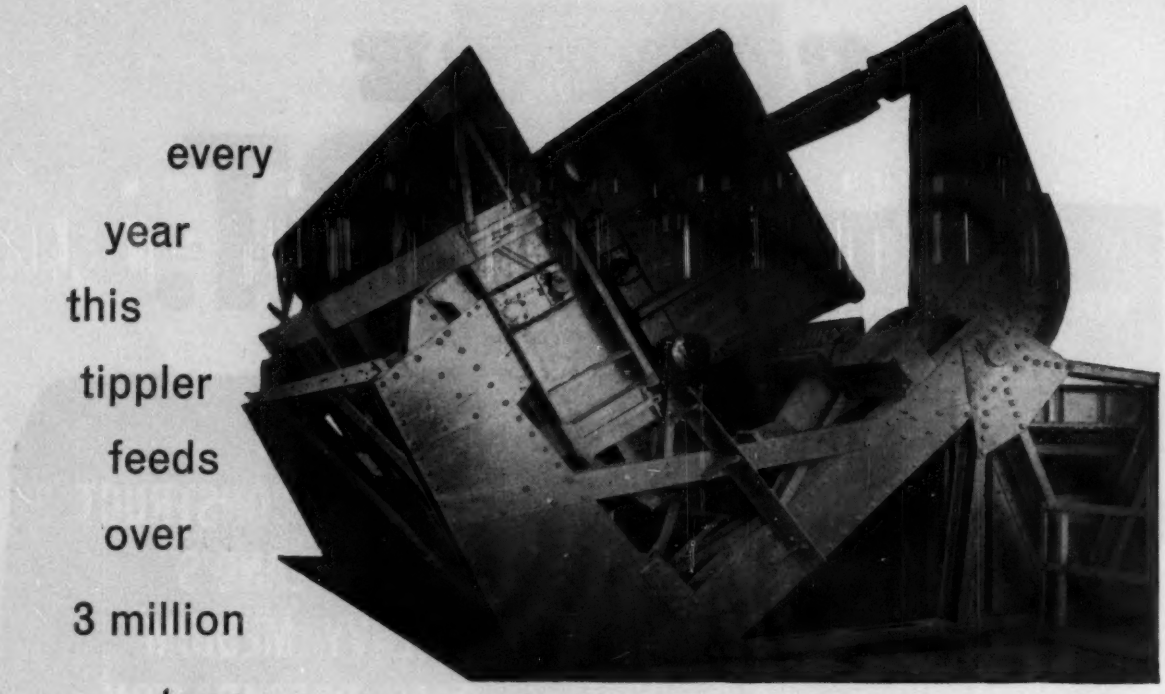
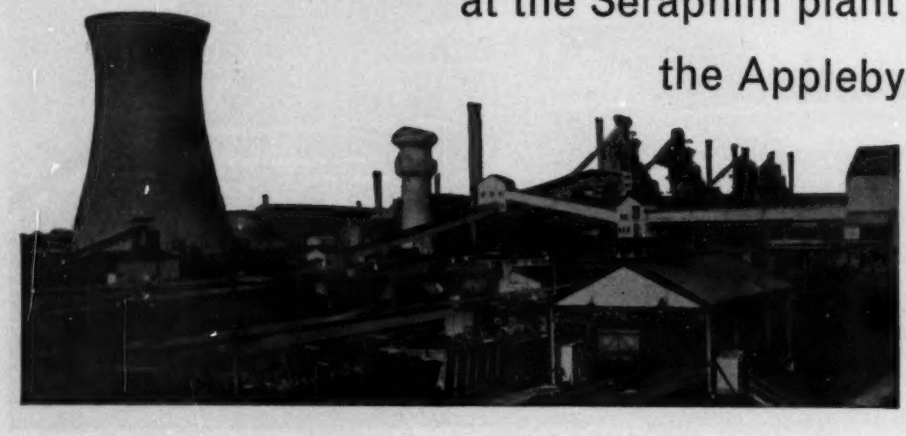
Company

Branch of the United Steel Companies Limited.





This complete ore-handling plant was commissioned in 1954 and is typical of many materials handling systems which have been installed all over the world.

G.E.C.

THE GENERAL ELECTRIC CO. LTD. OF ENGLAND · ERITH · KENT

DESIGNERS AND MANUFACTURERS OF COMPLETE MATERIALS HANDLING PLANT

MH236

Industry demands Steel —and Allen West Control Gear

Furnace tapping in the Electric Arc Melting Shop of Messrs Thos Firth & John Brown Ltd Sheffield, by whose courtesy this photograph is reproduced.

Whatever the application, for every motor there is an Allen West starter

ALLEN WEST

- **Designed to B.S. Specification throughout**
- **Complete range—A.C. or D.C. automatic or hand-operated, from fractional to thousands of horsepower**
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- **Crane Control Gear**
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Engineers and Manufacturers of Electric Motor Control Gear and Switchgear
SUBSIDIARY COMPANIES IN CANADA, SOUTH AFRICA AND RHODESIA · AGENCIES THROUGHOUT THE WORLD

New Landmarks

IN BOILER DESIGN

240,000 lb/hour at 3,300 p.s.i. and 1,060°F

860,000 lb/hour at 1,600 p.s.i. and 1,010°F

Simon-Carves Ltd have broken new ground
with two recent orders for boiler plant.
At Margam, for the Steel Company of Wales,
they are building a once-through forced circulation boiler
to generate 240,000 lb of steam per hour at 3,000 p.s.i.
and 1,060°F with reheat to 840°F.
This is the first Benson-type boiler to be built in
Britain and the steam conditions are the most advanced
ever commercially used in this country.
At the Padiham 'B' power station of the
Central Electricity Generating Board, Simon-Carves are to build
a 120-MW reheat boiler unit of the continuous-slagging type.
This unit, which will generate 860,000 lb per hour
of steam at 1,600 p.s.i. and 1,010°F
with reheat of 785,000 lb per hour to 1,005°F,
will be one of the first, if not actually the first,
of this type to be built in this country.
It will convert the whole of the ash and the dust
into slag and thereby both avert the nuisance
of handling and disposing of fine ash
and produce a usable product.
At the same time, Simon-Carves are busy
at home and abroad on the design and construction of
conventional boiler plant—a speciality in which
they have long played a leading part.

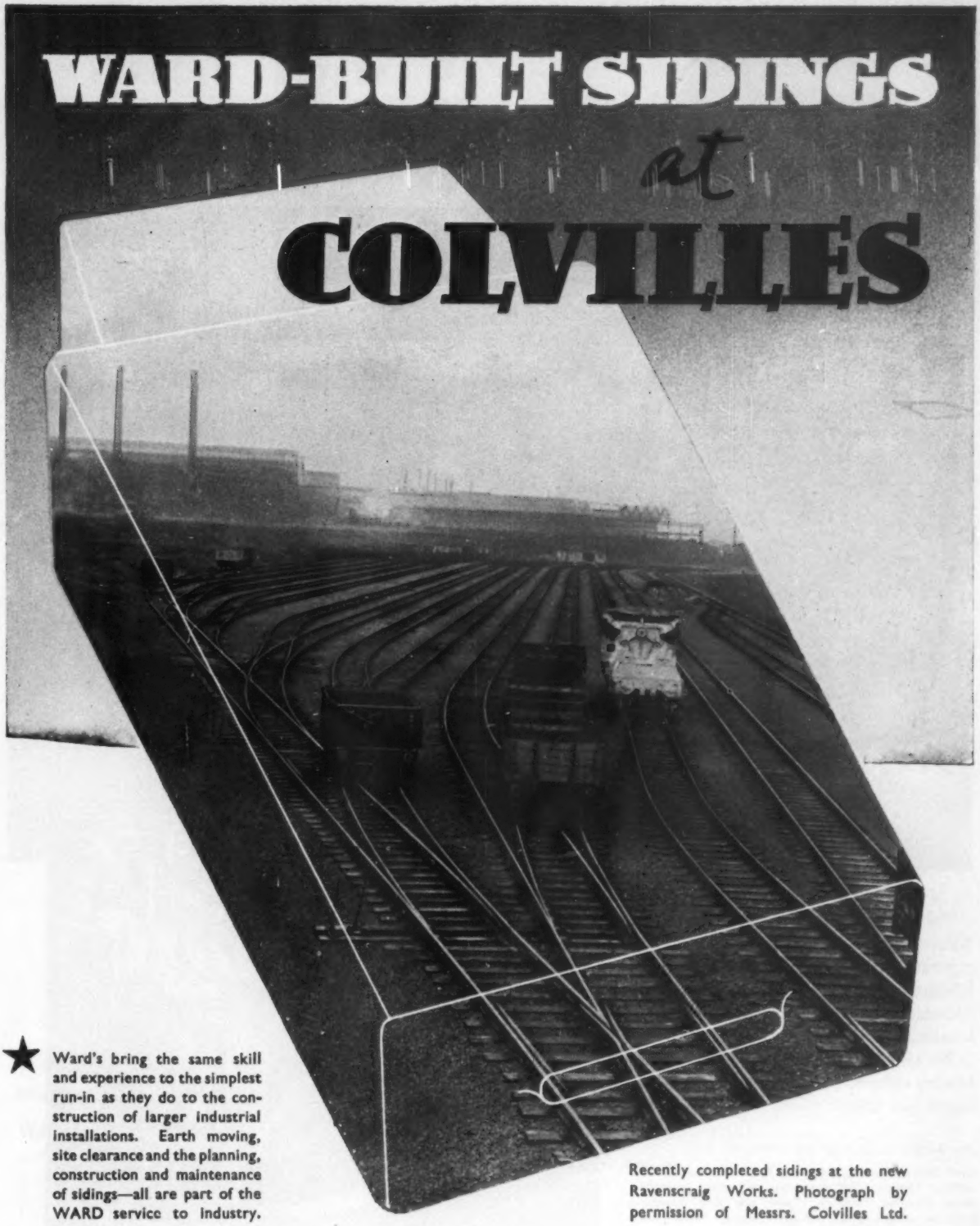
Complete power plant
by ***Simon-Carves Ltd***

SIMON CARVES GROUP

STOCKPORT, ENGLAND

OVERSEAS COMPANIES | Simon-Carves (Africa) (Pty) Ltd : Johannesburg Simon-Carves (Australia) Pty Ltd : Botany, N.S.W

WARD-BUILT SIDINGS at COLVILLES



★ Ward's bring the same skill and experience to the simplest run-in as they do to the construction of larger industrial installations. Earth moving, site clearance and the planning, construction and maintenance of sidings—all are part of the WARD service to industry.

Recently completed sidings at the new Ravenscraig Works. Photograph by permission of Messrs. Colvilles Ltd.

THOS. W. WARD LTD

ALBION WORKS · SHEFFIELD
'PHONE 26311 (22 lines). 'GRAMS 'FORWARD SHEFFIELD'
LONDON OFFICE: BRETTENHAM HOUSE
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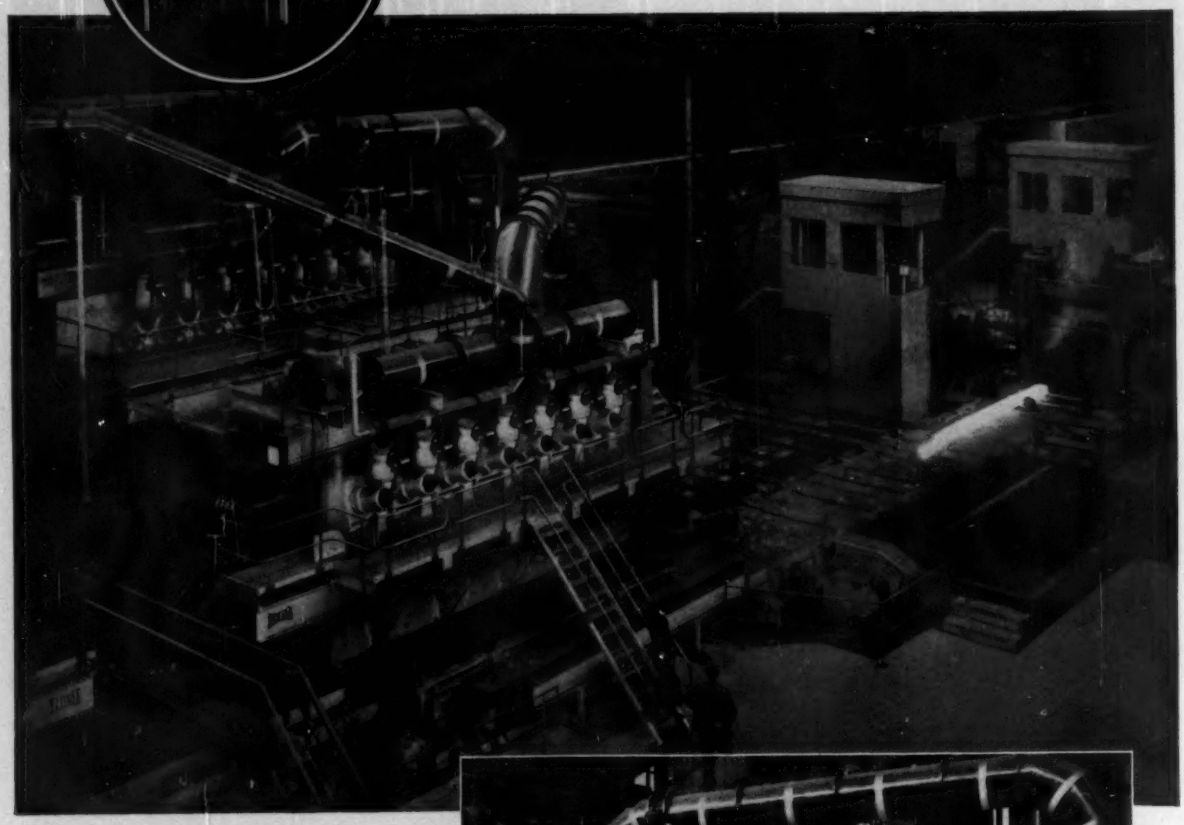
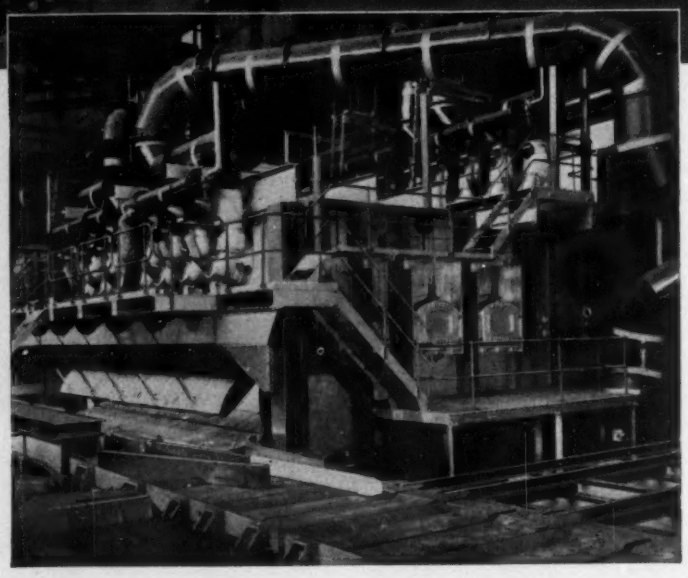
SC.49

PRIEST

3 zone Bloom Re-heating Furnaces





The photographs show one of two Priest 3-Zone Continuous type gas fired recuperative Bloom Re-heating Furnaces for Medium Section Mill. Installed at the Cleveland Works of Dorman Long (Steel) Limited.

We also supply similar Furnaces for re-heating slabs or blooms suitable for gas or liquid fuel firing.

We specialise in the design and construction of:—

Open Hearth Furnaces. Soaking Pits. Furnaces for Aluminium Melting, Coil Annealing and Slab Re-heating. Stress Relieving Furnaces. Forge and Heat Treatment Furnaces. Shipyard Plate and Bar Furnaces. Mould Drying Stoves. Modern Lime Burning Kilns.

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F111

selected fabrics...

selected resins...

and 21 years' in-built experience

When a bearing is made for a steel rolling mill, it's not just a choice between asbestos and some other fabric, or between one synthetic resin and another, that decides the suitability of the material for the job in hand. There are more than 16 grades of RAILKO: all embody 21 years of research and practical experience.

When you want the right material for a specific rolling mill bearing application, for longest life under onerous conditions, call in the RAILKO technician.

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participates in the research, technical, and productive resources of the Birfield Group, which includes Hardy Spicer, Laycock Engineering, Forgings and Presswork, The Phosphor Bronze Co. Ltd., and other famous companies.

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bearings for steel rolling mills

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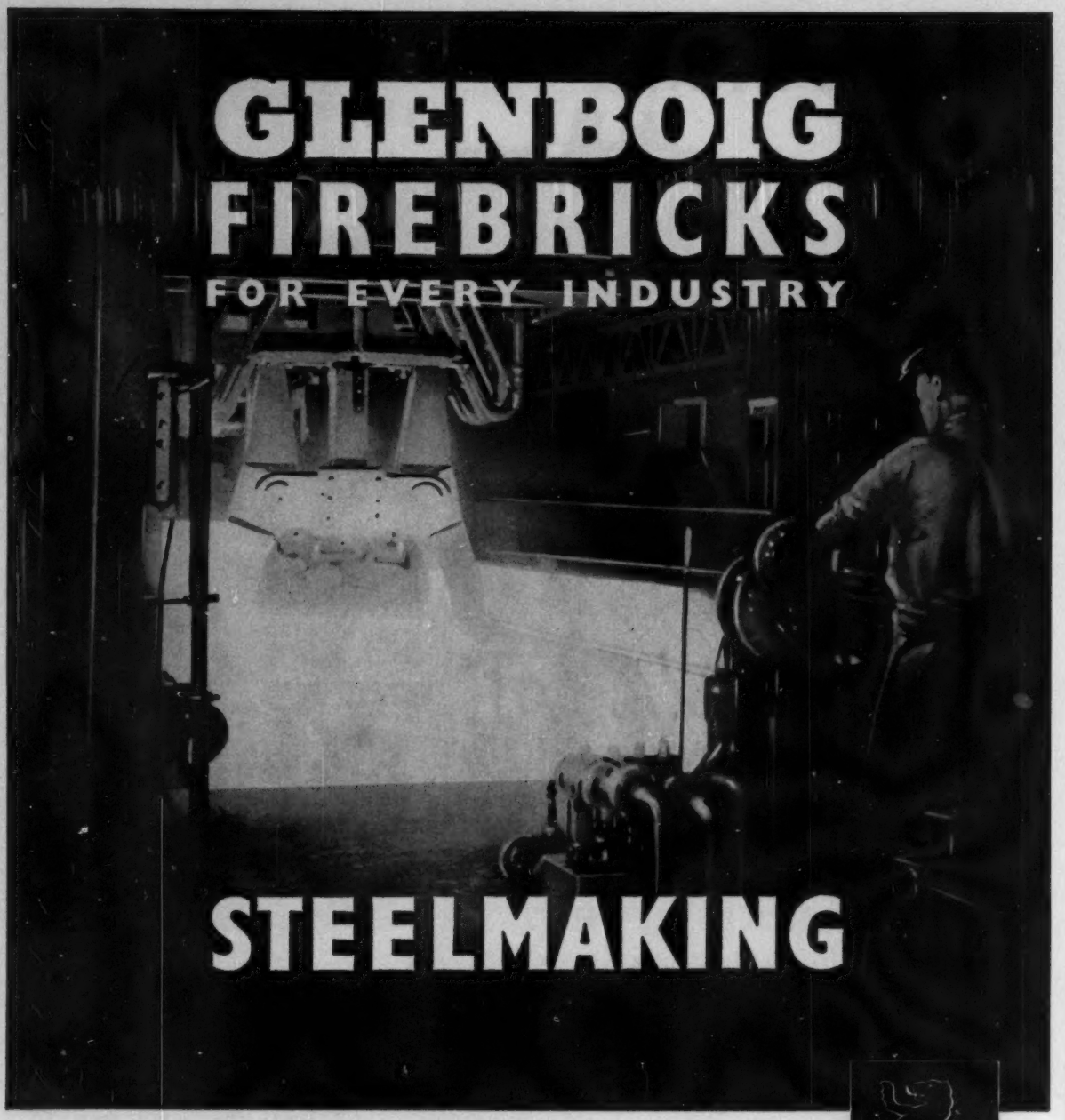

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THE GLENBOIG RANGE INCLUDES:

42/44% Al_2O_3 **GLENBOIG A1 · GLENBOIG A1 CROWN**
36/38% Al_2O_3 **GLENBOIG · GLENBOIG CROWN · CASTLECARY**
33/34% Al_2O_3 **DYKEHEAD · GEM**

THE GLENBOIG UNION FIRE CLAY CO. LTD., GLENBOIG, LANARKSHIRE, SCOTLAND
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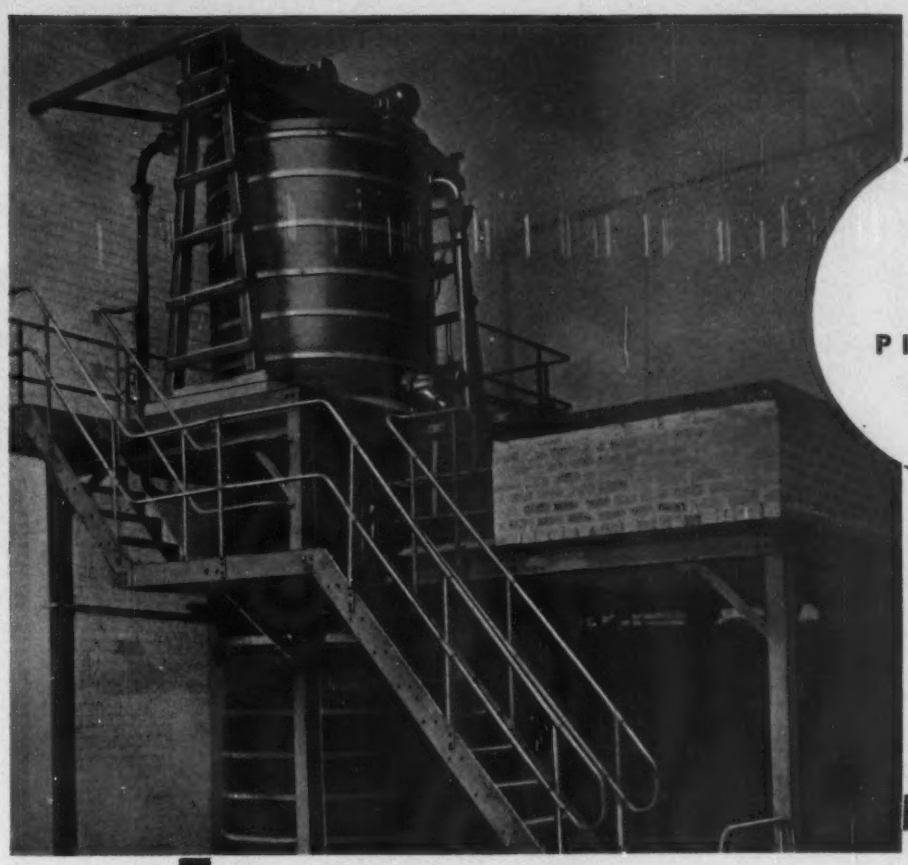

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KESTNER-FAKLER acid-recovery plant

The advantages of Kestner-Fakler acid recovery plant are:—

1. The Kestner-Fakler acid recovery plant can be operated by unskilled labour and requires no special attention.
2. Requires little maintenance as the number of parts are limited.
3. Is manufactured in the well-known Kestner plastic constructional material Keebush, completely inert to the action of sulphuric acid pickling liquor.
4. Pays for itself within a few years and the initial installation is low in first cost.
5. Gives very uniform working and avoids over or under pickling.
6. Enables all acid normally thrown to drain to be recovered.
7. Overcomes effluent disposal problems and, as such, is favoured by Local Authorities.

Kestner
THE CHEMICAL ENGINEERS

Can be fitted to all types of pickling plant. Send for full details to:—

KESTNER EVAPORATOR & ENGINEERING CO. LTD.

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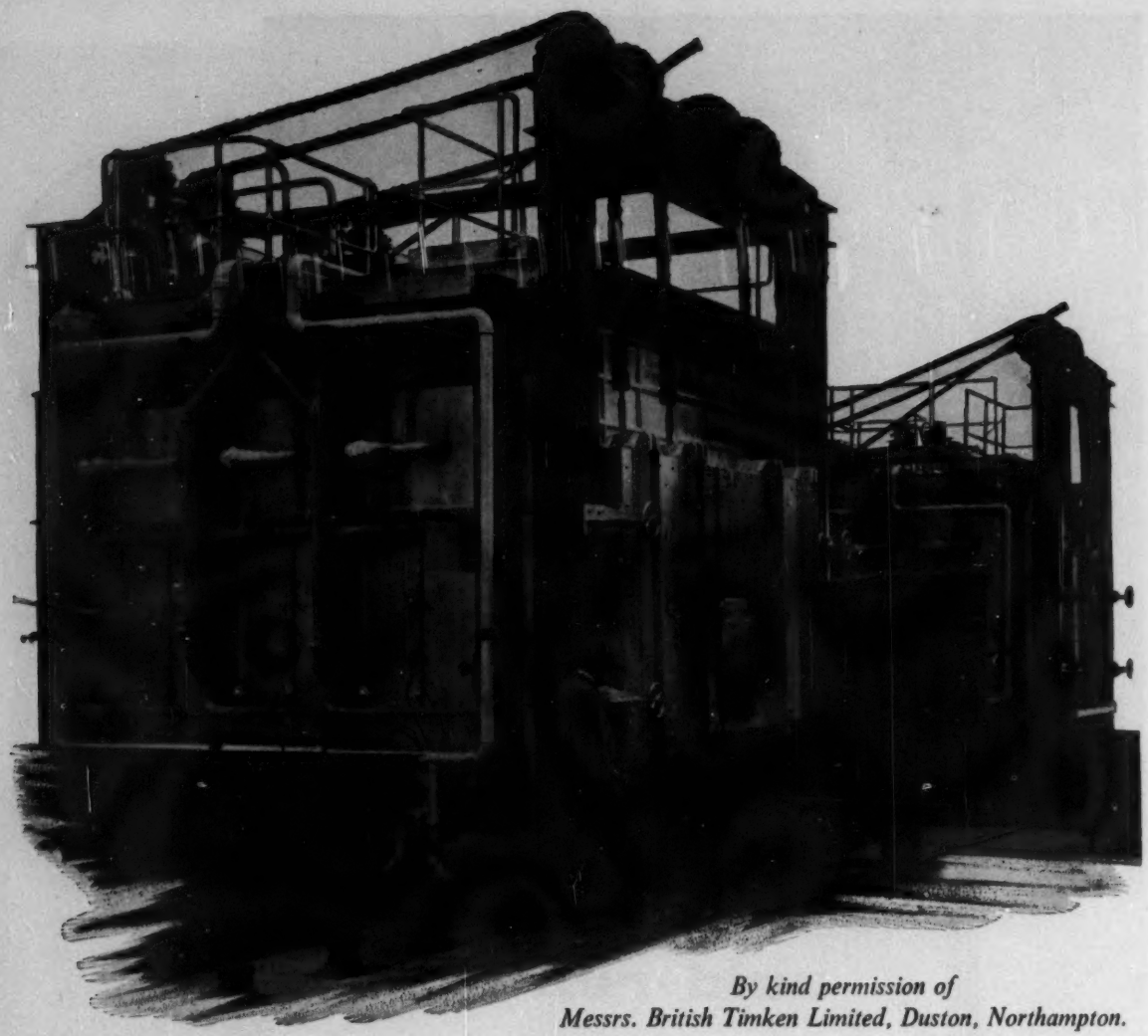

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Messrs. British Timken Limited, Duston, Northampton.

GAS FIRED CARBURISING FURNACES BY

This is part of a plant, installed at Daventry, comprising Two Furnaces, mobile and fixed loading tables and a Gibbons-van Marle Charging Machine.

The Furnace shewn can take work up to 9′6″ diameter x 3′0″ deep.

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SCIENCE AND THE STEEL TUBE AGE: 6

S&L

DESIGN OF BRANCH PIECES

The reinforcement of branch and junction pieces in steel pipes for a long time presented a difficult problem; some years ago our Research department investigated various types in current use and evolved a design of their own which has proved highly satisfactory. This, known as the 'triform' reinforcement, embodies three horseshoes embracing the junction between the pipes.

To test the adequacy of such reinforcements against internal pressure, special testing pumps are in use in our Research department at Corby; these are capable of exerting pressures up to 27,000 lb./sq. inch under sensitive and accurate control.

The illustration shows such a test being carried out on a welded 'Y' piece with a triform reinforcement. Before internal hydraulic pressure is applied the 'Y' piece is coated with plumber's resin. As the pressure increases a stage is reached when small cracks, indicating the presence of Lüders' slip lines in the material, appear in the resin (see insert) thereby showing those points at which yielding has occurred. From the disposition of these slip lines much can be learned about the stresses in the material, and the information obtained leads to efficient and simple designs of adequate strength.

STEWARTS AND LLOYDS LIMITED

GLASGOW · BIRMINGHAM · LONDON

BUILT FOR EXPORT TO AUSTRALIA

The Austral Bronze Company Pty. Ltd., of Alexandria, N.S.W., Australia, has installed a 14 in. and 36 in. by 44 in. four-high mill as illustrated for the cold-rolling of copper and brass strip.

The mill was designed and built by The Loewy Engineering Co. Ltd., England, and was commissioned in February, 1956.

It has Timken tapered-roller bearings on the back-up and work rolls.

TIMKEN REGD. TRADE MARK *tapered-roller bearings*

MADE IN ENGLAND BY BRITISH TIMKEN LTD

DUSTON, NORTHAMPTON (Head Office); DAVENTRY & BIRMINGHAM

Telephone: Northampton 4921-8 and 3452-3. Telex No. 31-620. *Telegrams:* Britimken Northampton Telex.
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SCHLOEMANN

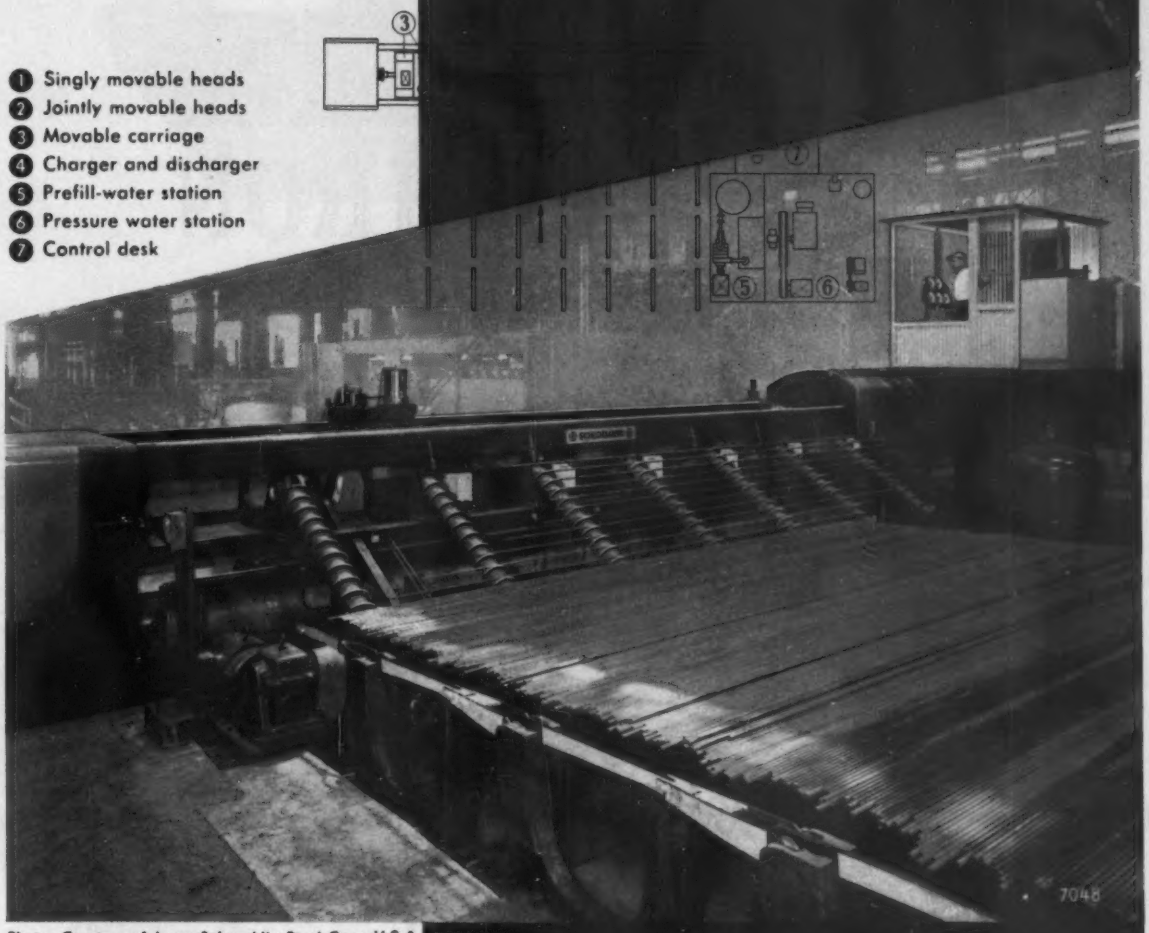

Photo: Courtesy of Jones & Laughlin Steel Corp. U.S.A.

An outstanding machine now in successful operation at Jones & Laughlin Steel Corporation is the Automatic SCHLOEMANN Five-Tube Tester. Up to 1,200 tubes per hour can be hydrostatically tested in this machine, by either the face-sealing, or cup-sealing method. Automatic defective tube sorting device can be furnished. Only one operator needed. *For complete information send for leaflet 31/1e.*

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BUILT FOR EXPORT TO AUSTRALIA

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TIMKEN REGD. TRADE MARK *tapered-roller bearings*

MADE IN ENGLAND BY BRITISH TIMKEN LTD

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Telephone: Northampton 4921-8 and 3452-3. Telex No. 31-620. *Telegrams*: Britimken Northampton Telex.

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SCHLOEMANN

1. Singly movable heads
2. Jointly movable heads
3. Movable carriage
4. Charger and discharger
5. Prefill-water station
6. Pressure water station
7. Control desk

Photo: Courtesy of Jones & Laughlin Steel Corp. U.S.A.

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PIG IRON

containing 12/14% Silicon (or required content)

- Clean Machine Cast Pigs
- Dense Fracture
- No free graphite
- Guaranteed analysis
- Prompt delivery

WARNER

"Pioneers of Refined Pig Iron"

WARNER & CO. LTD., MIDDLESBROUGH

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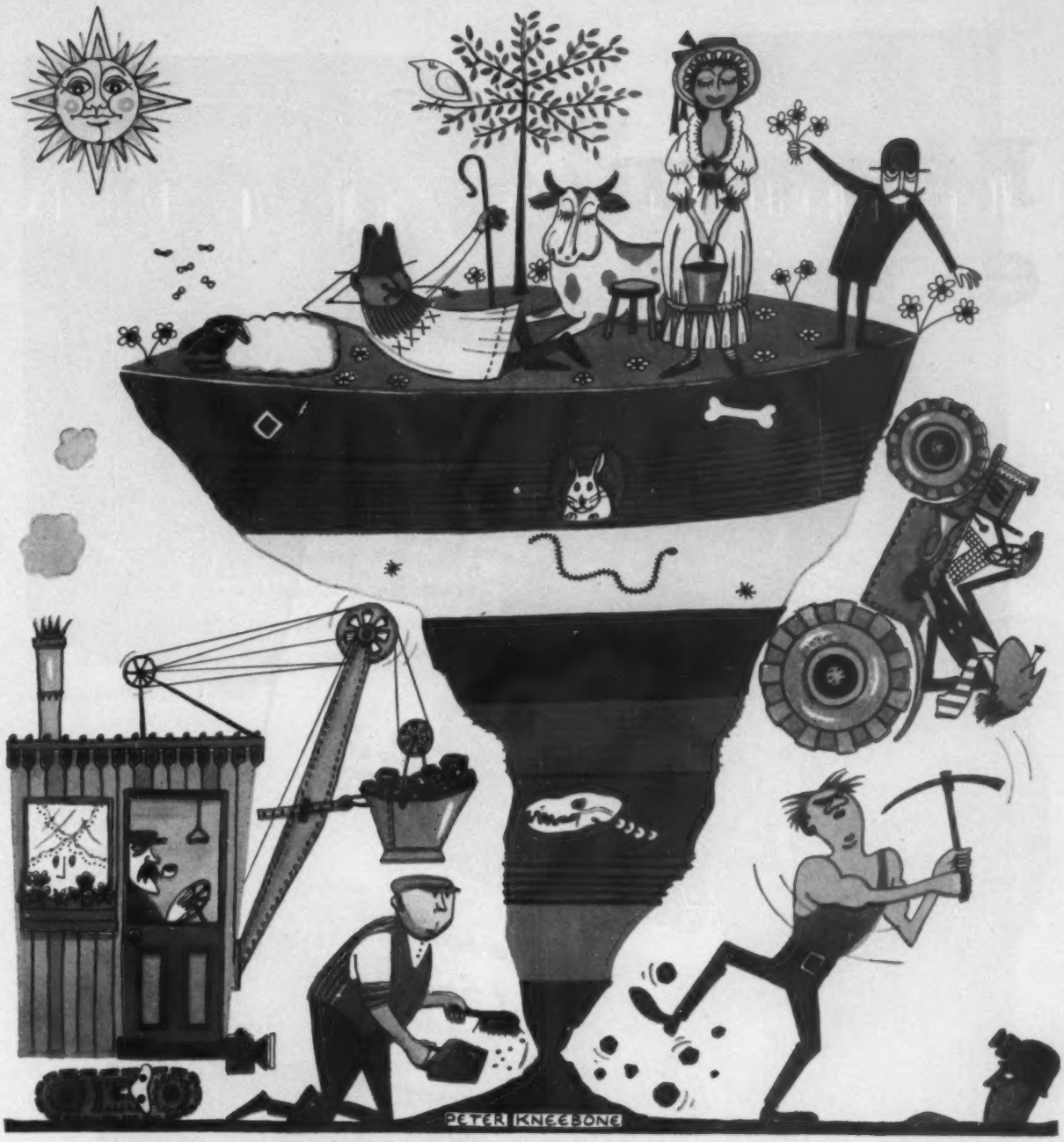

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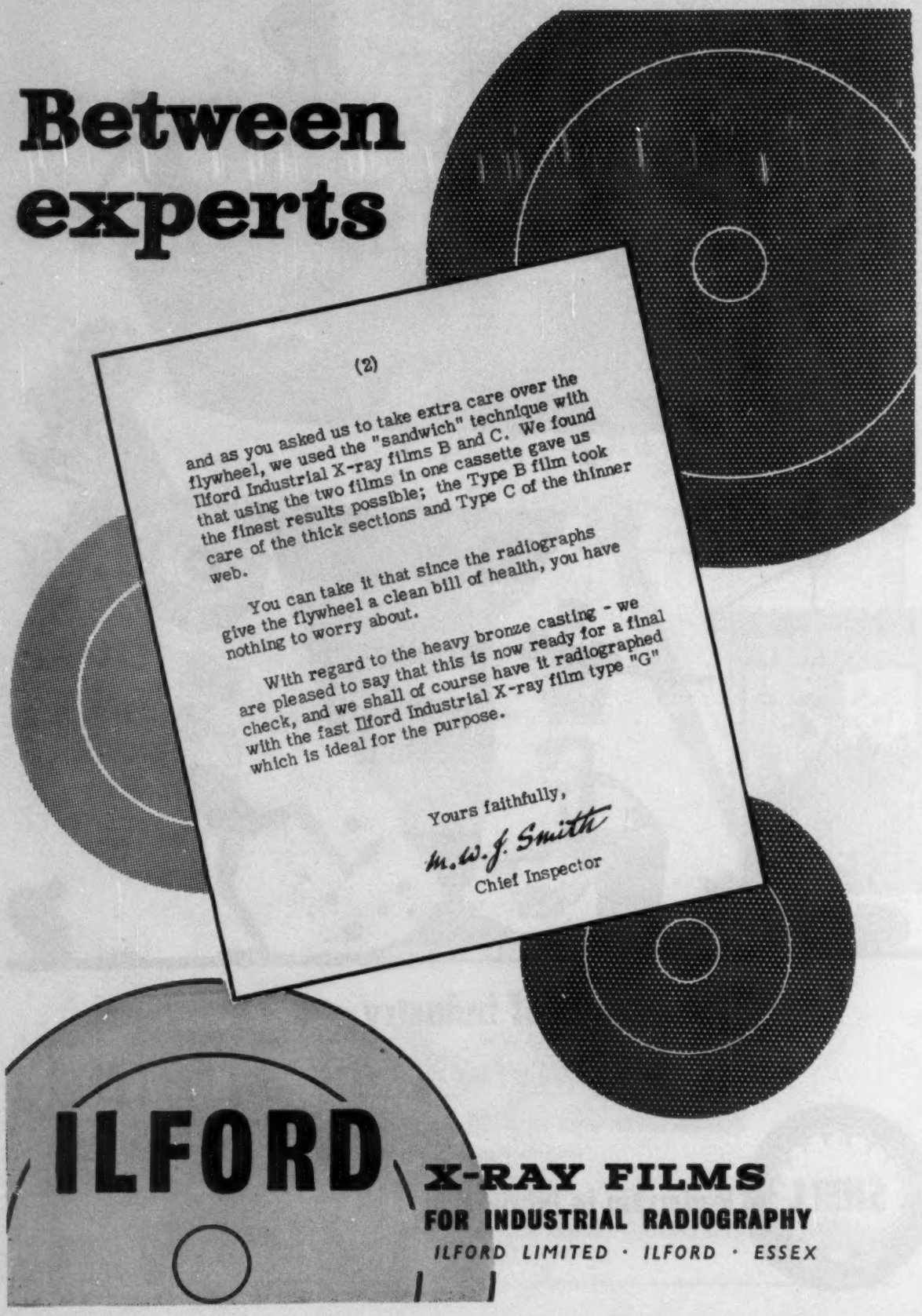
OPEN-CAST MINING

For every modern industrial process there is a specialised grade of Sea Shell Lubricant.

SHELL leadership in lubrication

Copies of this advertisement (in colour) can be obtained from Shell-Mex and B.P. Ltd.

Between experts


(2)
and as you asked us to take extra care over the flywheel, we used the "sandwich" technique with Ilford Industrial X-ray films B and C. We found that using the two films in one cassette gave us the finest results possible; the Type B film took care of the thick sections and Type C of the thinner web.
You can take it that since the radiographs give the flywheel a clean bill of health, you have nothing to worry about.
With regard to the heavy bronze casting - we are pleased to say that this is now ready for a final check, and we shall of course have it radiographed with the fast Ilford Industrial X-ray film type "G" which is ideal for the purpose.
Yours faithfully,
M. W. J. Smith
Chief Inspector

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FOR INDUSTRIAL RADIOGRAPHY

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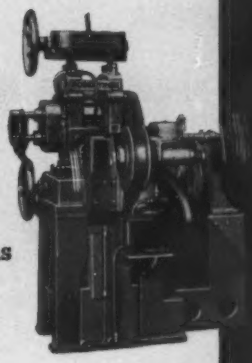
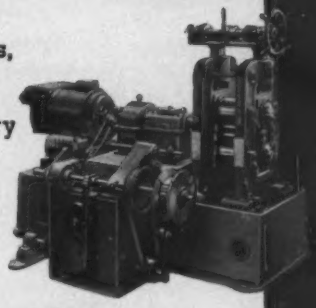
MAN AND MACHINES

Man perforce has become a designer of machines. Machines which will help him produce more goods more speedily. After he produces faster, he needs more accuracy, greater versatility. Especially if he happens to work in metals, in sheets or strips, wires or tubes.

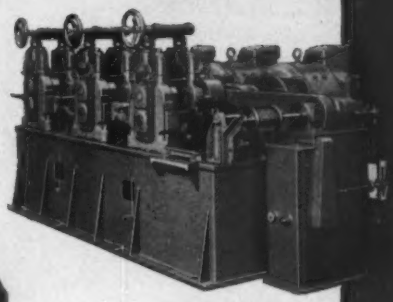
Robertson's equipment for reducing steel, aluminium and other metals into sheets, strips, wires and tubes, has developed consistently throughout the last half century in advance of man's requirements. Today, their high quality, precision machinery designed for sustained output is found throughout the world, wherever men are working metals.



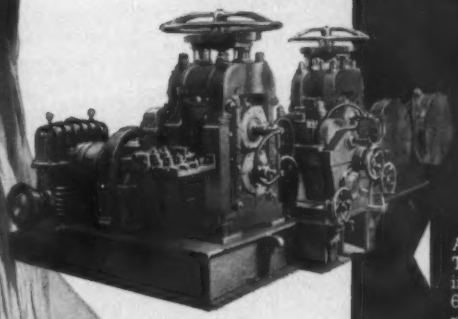
A small Two-High Mill with rolls 4" diameter, 3" face.



A Four-High Single Stand Mill with work rolls 2¼" diameter, 4" face, and support rolls 6¼" diameter, 4" face.

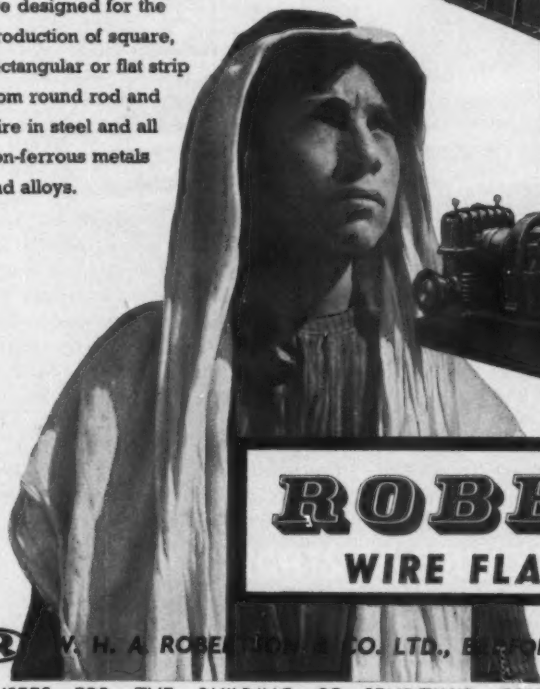


A Three-Stand Tandem, each stand individually motor driven and having rolls 6¼" diameter, 4" face.



A No. 2 Tormanco Tandem, with roughing rolls 10" diameter, 6" face, and finishing rolls 8" diameter, 6" face

The examples illustrated are from the range of Robertson Mills, which are designed for the production of square, rectangular or flat strip from round rod and wire in steel and all non-ferrous metals and alloys.



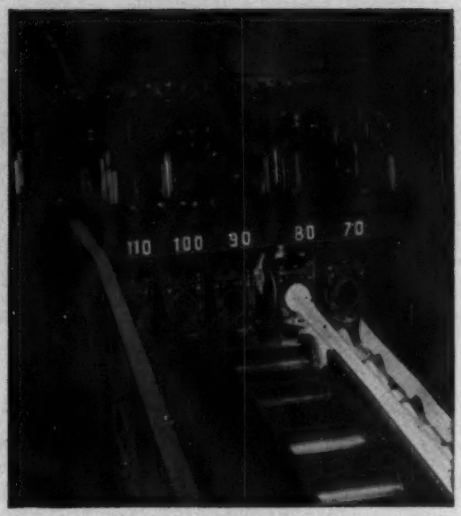
ROBERTSON

WIRE FLATTENING MILLS

(R) W. H. A. ROBERTSON & CO. LTD., BEDFORD, ENGLAND

LICENSEES FOR THE BUILDING OF SENDZIMIR COLD REDUCTION MILLS & PLANETARY HOT MILLS, HALLDEN FLYING SHEAR MACHINES AND TORRINGTON WIRE FLATTENING AND EDGING MILLS. W.T. 303

...od reasons
...y you should use these
ROLLER GUIDES
in your bar or wire
rod mill



Nos. 125 and 155 roller guides fitted in a 27 1/2 in. (700 mm.) diameter, three-high stand for rolling 2 3/4, 3 3/16, 3 9/16, 4, 4 3/8 and 4 7/8 in. (70, 80, 90, 100, 110 and 124 mm.).

1 The entry friction guides are rigidly clamped into the guide box. They are intended to lead the oval to the groove in the roller, to protect the rollers against overloading, and to straighten bent rods.
The groove in the entry guides is made about 1/8" wider than the oval.

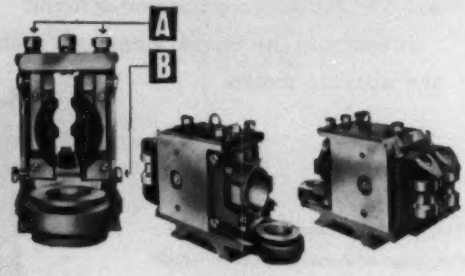
2 The rollers are mounted on leaf springs, which can be adjusted by means of the screws "B", and hold the oval steadily even if there should be some slight variation in the thickness of the oval.

3 If the thickness of the oval should vary, the springs of both rollers yield an equal amount, so that the oval remains in the centre of the groove.

4 To tilt the oval, the screws "A" are adjusted. One roller will then be lifted as much as the other is lowered.

5 As the oval is held very rigidly, the leader oval for wire rod may be thick, unless other circumstances call for a thinner oval.

6 The roller guide assemblies are narrow, and all screws that require adjustment during rolling are accessible from the front of the mill. No lateral space outside the guide box is therefore required for gaining access to the set screws, and the guide box assembly can thus be located close to the mill housing.



7 As the groove in the entry guides is wide and nothing but rolling friction acts on the oval, the latter is very easily introduced into the pass, and there is practically no risk of scratching the bar.

8 The roller guide may be used not only for leader and drawing oval passes but also for edging flats as well as for rolling squares, hexagons, octagons and various other sections, for instance in reduction passes for hexagon. It is suitable for all types of rolling mill. An important advantage is that the roller guide enables repeaters to be used in rolling plump leader-ovals.

PS *Practically speaking, every bar and wire rod mill in Scandinavia uses roller guides of our design.*

MORGÅRDSHAMMAR

MORGÅRDSHAMMARS MEK VERKSTADS AB • MORGÅRDSHAMMAR • SWEDEN

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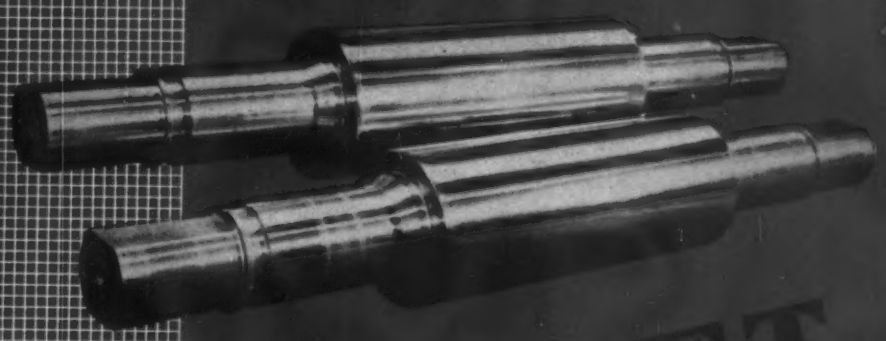
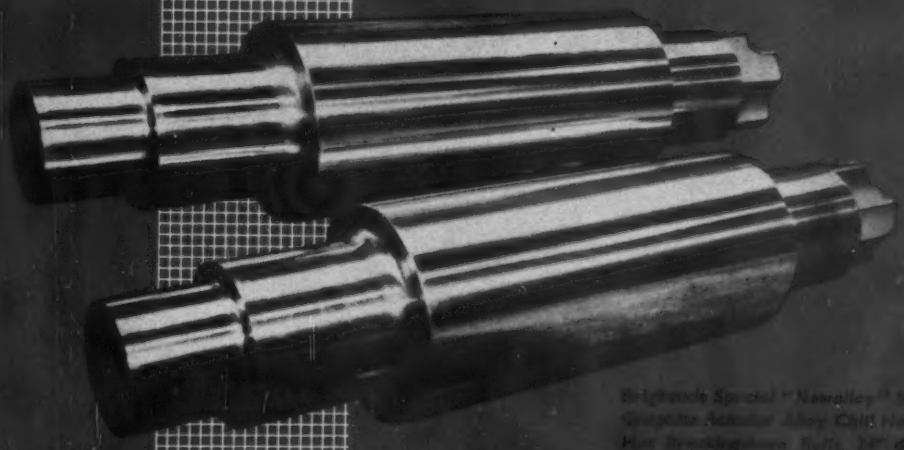
For the complete story — send for your copy of Bulletin L3-1E.

BRIGHTSIDE

ROLLCRAFT

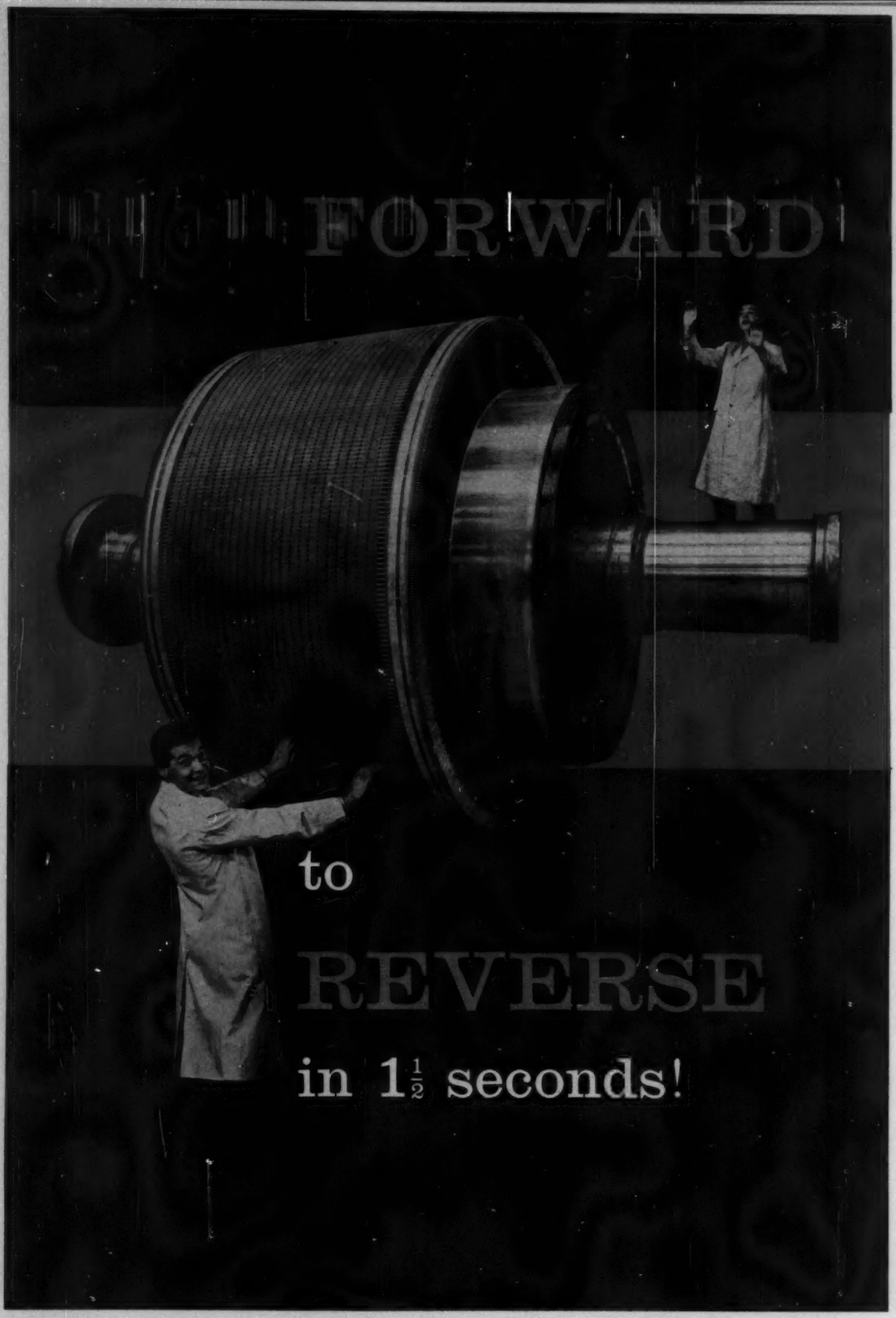
The Brightside range of rolls for hot and cold rolling is keeping pace with the exacting requirements of the steel and non-ferrous industries at home and abroad.





THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD.

G.P.O. BOX 116, SHEFFIELD 1.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to
REVERSE
in 1½ seconds!

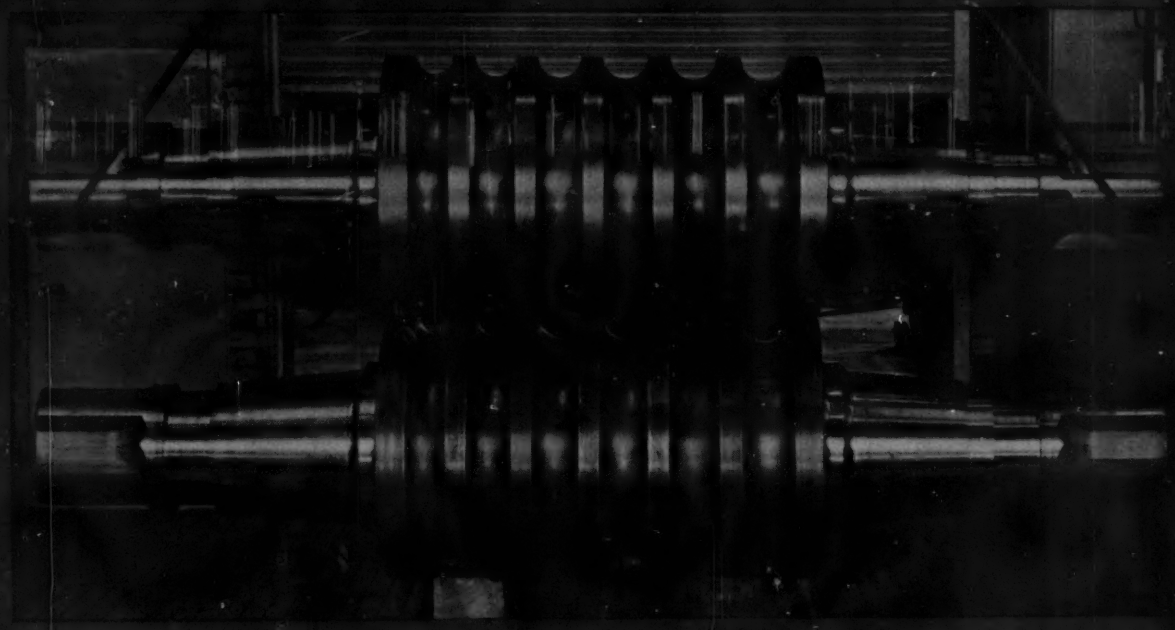
A small lever is moved , and 58 tons of armature reverse. From a base speed of 50 r.p.m. one way to 50 r.p.m. in the opposite direction. In 1½ seconds. This giant G.E.C. 5,000 h.p. motor is driving a cogging mill at the Redbourne Steel Works of Richard Thomas and Baldwins Ltd. It typifies the speed and precision of the electric drive.

Less spectacular than the mammoth motors but equally important to steel production are the many hundred auxiliary drives operating in a modern works where the utmost reliability is essential. Here, again, most of the handling requirements subject the equipment to very severe stresses. G.E.C. motors are as tough as the jobs they're designed to do.

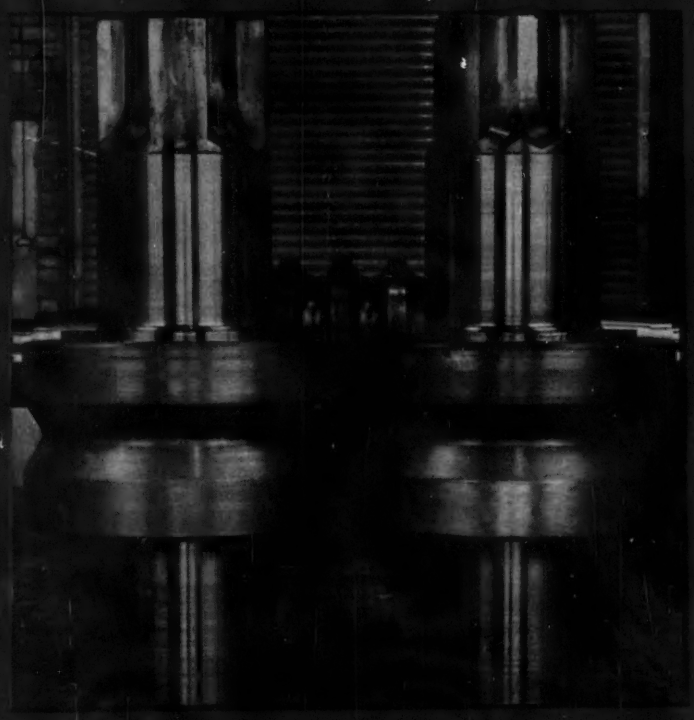
G.E.C. rolling mill motors

THE GENERAL ELECTRIC COMPANY OF ENGLAND
HEAD OFFICE: MAGNET HOUSE KINGSWAY LONDON W.C.2

INCREASED TONNAGE



A pair of our Special "S.G." Heat-resisting Cooling Rolls for Finishing Large Rounds 4½" to 6" Dia. for No. 6 Stand. Roll size 32" dia. x 54" long barrel.



The Specialised Products include:

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HOT & COLD ROLLING ALL CLASS
OF STEELS FOR SHEETS, STR
SECTIONS
AND
NON FERROUS METALS

SPECIAL ROLLS FOR STAINLES
STEEL ROLLING

PART CHILL, GRAIN & ALLOY GRA
ROLLS

ALSO THE S.G. RANGE O
SUPER TOUGH SPHEROIDA
GRAPHITE ALLOY IRON ROLL

No. 5 Vertical Edging Stand on our Mauri
"ESSDA" Quality for Build mess (diamond p
Louvre for 2" to 4" Billets.
Roll size 31½" dia. x 18" long barrel.

THE ROLL MAKERS

JOHN. M

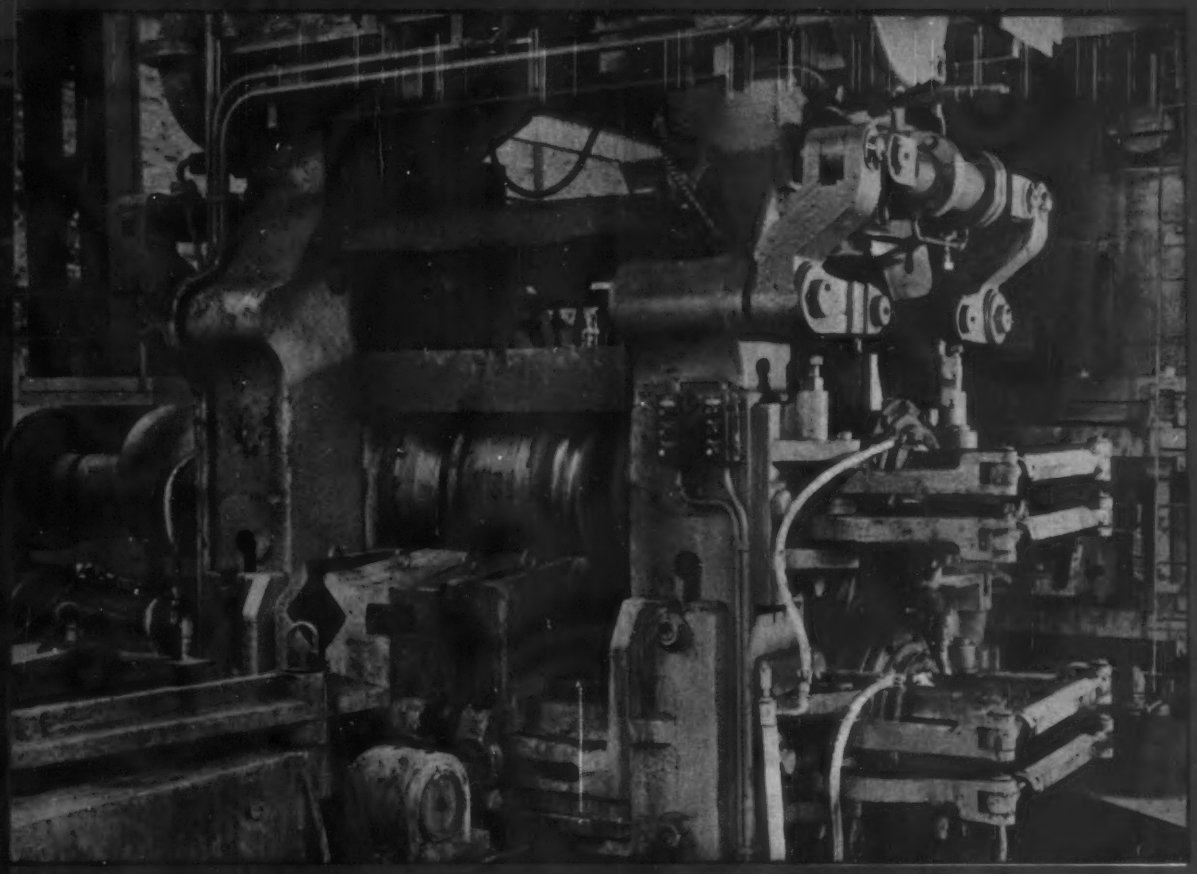
EAGLE FOUNDRY · STEVENSON RO

TELEPHONE: SHEFFIELD 43018

WITH

MOORALLOY

THE SUPER ROLL METAL



No. 6 Sheet Finishing for 4", 4½" and 5" Billets, also Roughing for 2" to 5" Billets and Slabs at Consett Iron Co., Ltd., showing one Special S.S.X. Mooralloy Quality Rolls. Roll size 32" dia. x 54" long barrel.

Photograph kindly by the courtesy of The Consett Iron Co. Ltd.

Considerable economies in materials, production time and maintenance costs can be effected by the use of our Mooralloy Rolls for Continuous Mills, idle time resulting from the need for redressing is reduced to a minimum.
It is necessary to select the correct quality from the very wide range now available to suit all the conditions in modern mill practice.

The "SSX" Range of Tough Metal
"SSX", "SSXM", "SSXH".

The "XL" Range of Tough Medium Hard Metal
"XLM", "XL", "XLH".

The "XXL" and "XXXL" Ranges of Hard Superfine Close Texture Metal
"XXL", "Super XXL", "XXXL", "Super XXXL".

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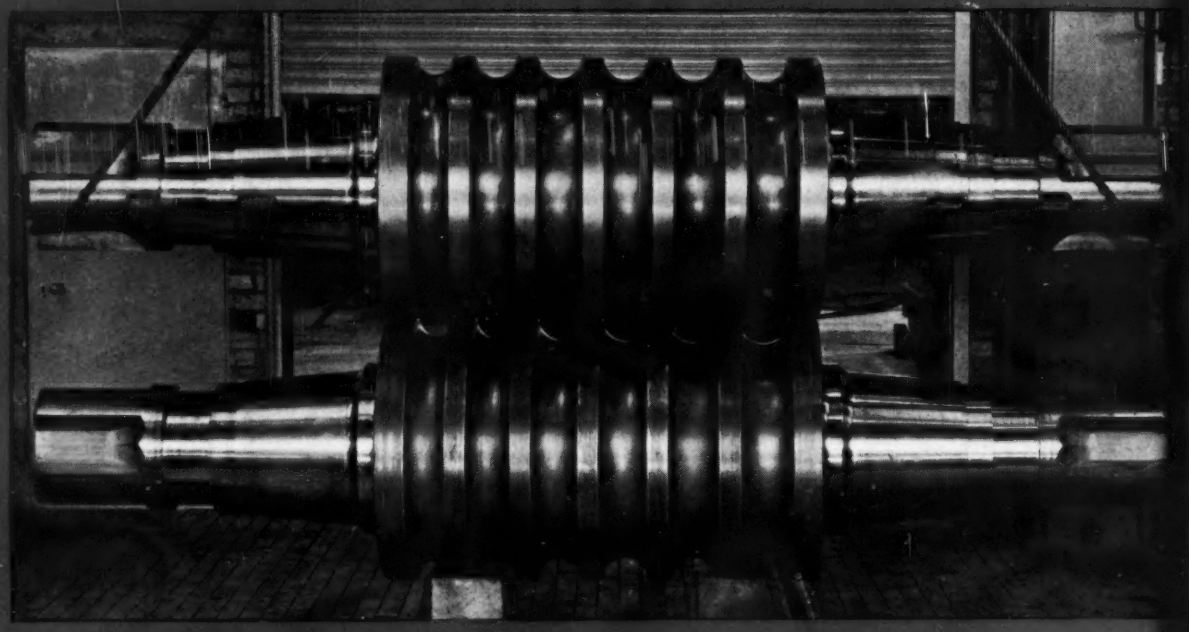
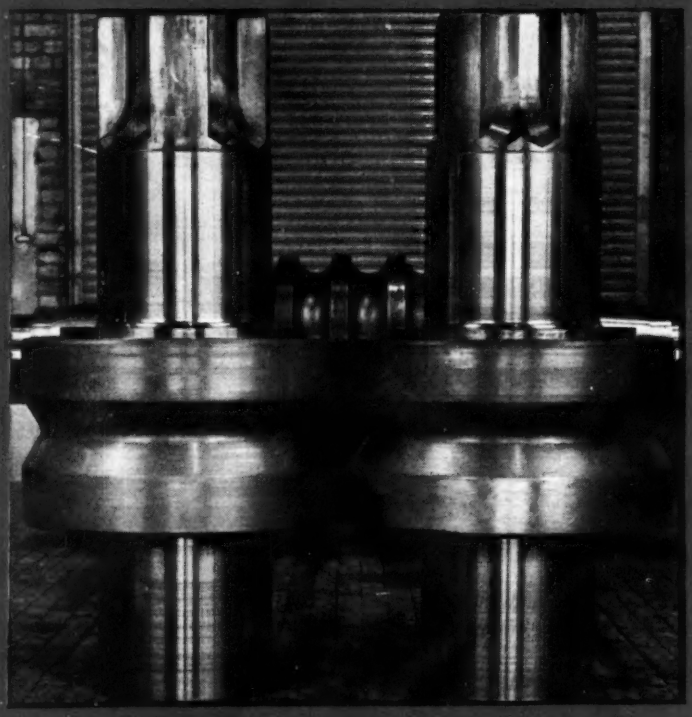


A pair of our Special "SSXH" Mooralloy Quality Rolls for Finishing Large Rounds 4½" to 6" dia. for No. 6 Stand. Roll size 32" dia. x 54" long barrel.



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CHILL AND ALLOY CHILL ROLLS FOR HOT & COLD ROLLING ALL CLASSES OF STEELS FOR SHEETS, STRIP SECTIONS,
AND
NON FERROUS METALS

SPECIAL ROLLS FOR STAINLESS STEEL ROLLING

PART CHILL, GRAIN & ALLOY GRAIN ROLLS

ALSO THE S.G. RANGE OF SUPER TOUGH SPHEROIDAL GRAPHITE ALLOY IRON ROLLS

No. 5 Vertical Edging Stand in our Moorallo "SSXM" Quality for Billet train (diamond pa Leader for 2" to 4" Billets. Roll size 31½" dia. x 18" long barrel.

THE ROLL MAKERS

JOHN. M

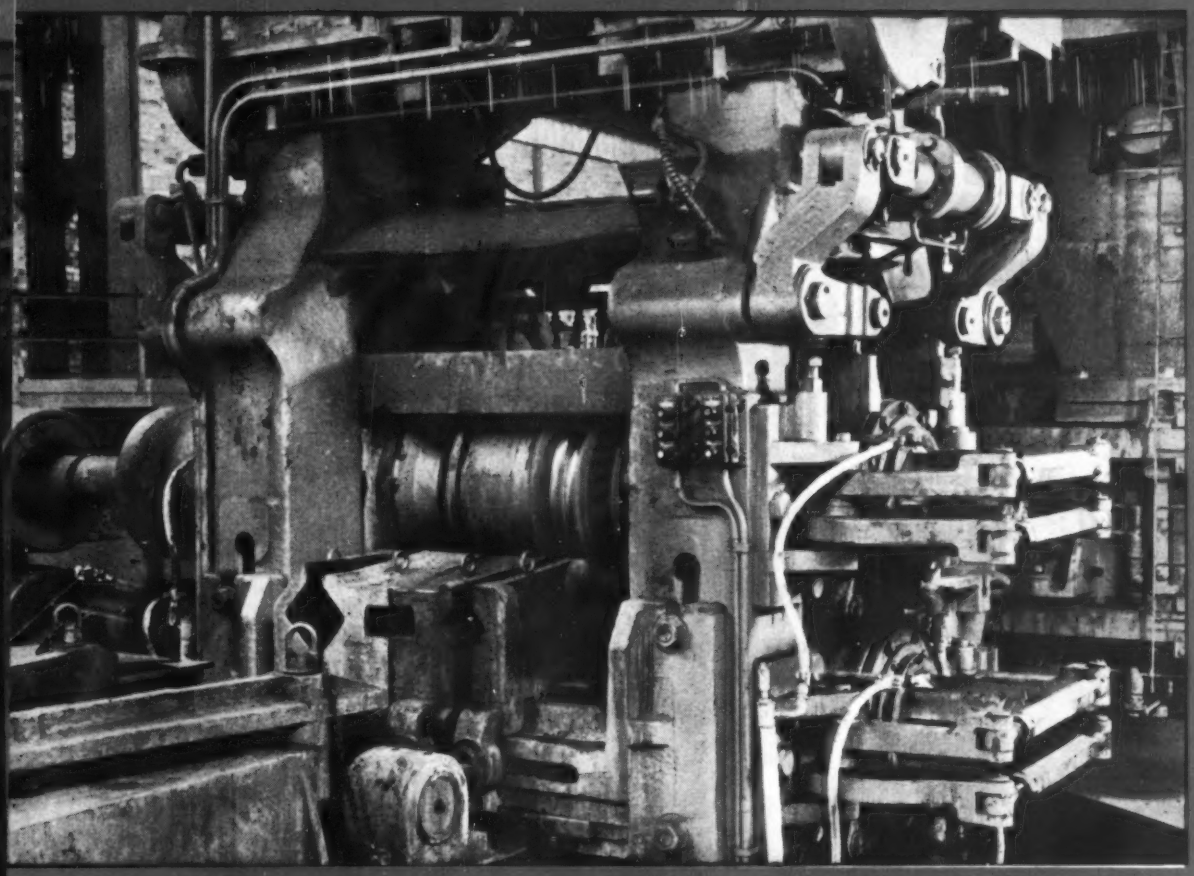
EAGLE FOUNDRY • STEVENSON ROA

TELEPHONE: SHEFFIELD 42018

WITH

MOORALLOY

THE SUPER ROLL METAL



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The "XXL" and "XXXL" Ranges of Hard Superfine Close Texture Metal
"XXL", "Super XXL", "XXXL", "Super XXXL".

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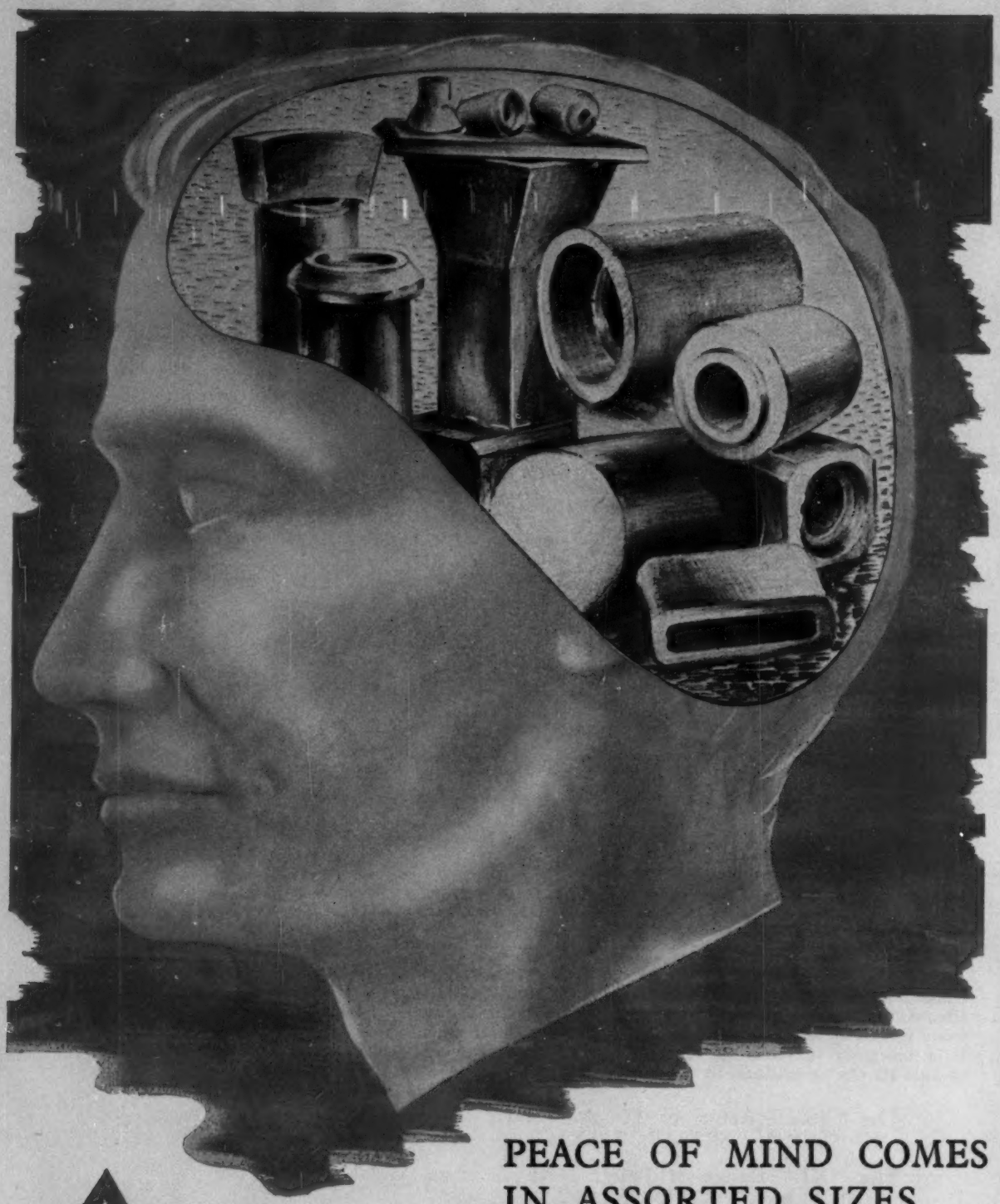

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Small coupling diameter means a low WR²—a very important factor in reversing mills—shafts up to 32" diameter can be accommodated.

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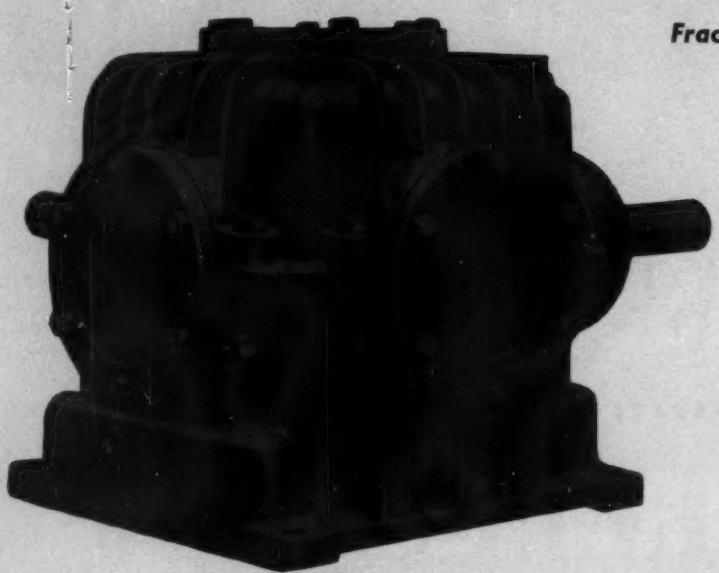

Fractional to 1100 h.p.; ratios 1 : 1 to 5 : 1

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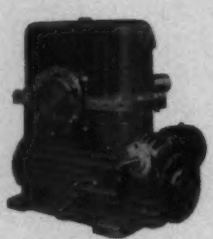

Combined double reduction worm gears

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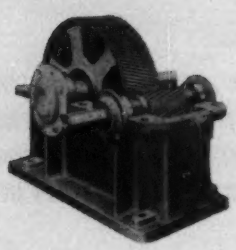

Single helical gear units

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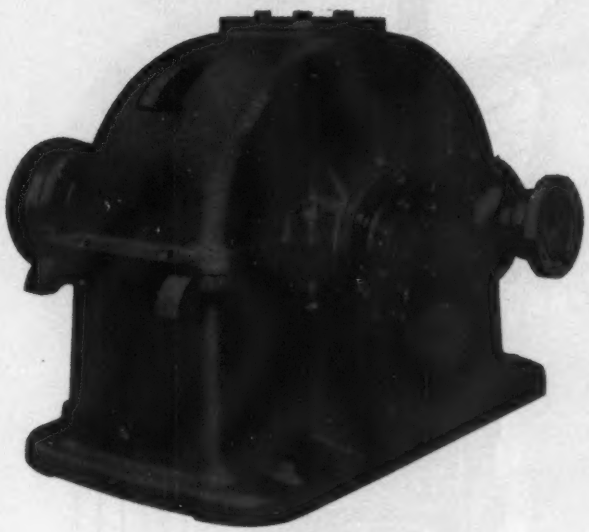

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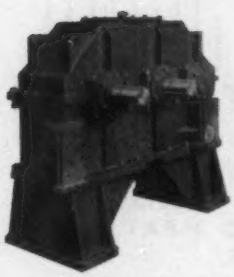

special fabricated gear units

all types for every duty

medium power turbine gears

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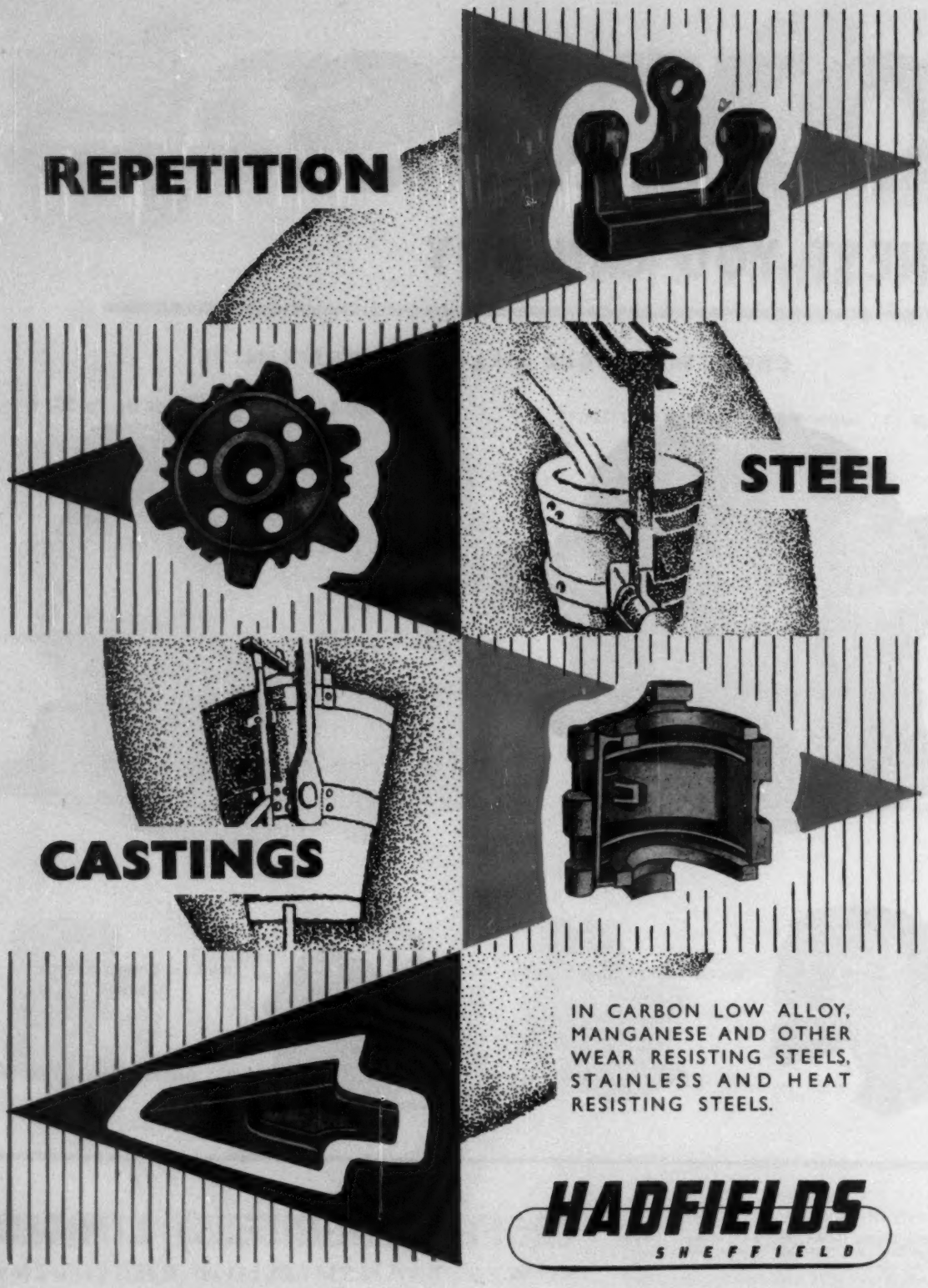

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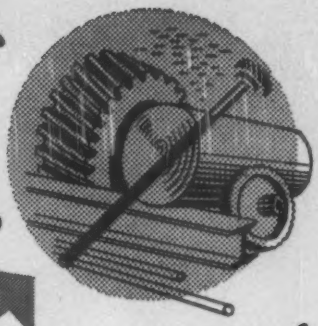
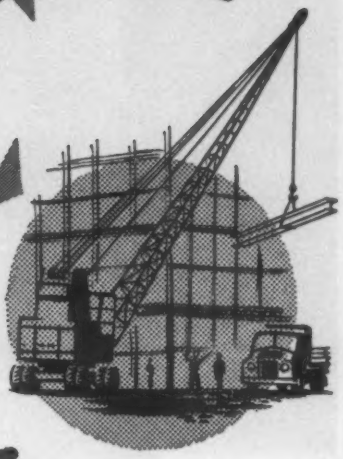
HADFIELDS LTD., EAST HECLA WORKS, SHEFFIELD, ENGLAND.

Scrap clearance..



dismantling.....



CONTACT

COX AND DANKS LIMITED

BIRMINGHAM
Scapa Works
Langley Green
Oldbury, Birmingham
Tel: Broadwell 1611

MANCHESTER
Frederick Road
Pendleton
Salford 6
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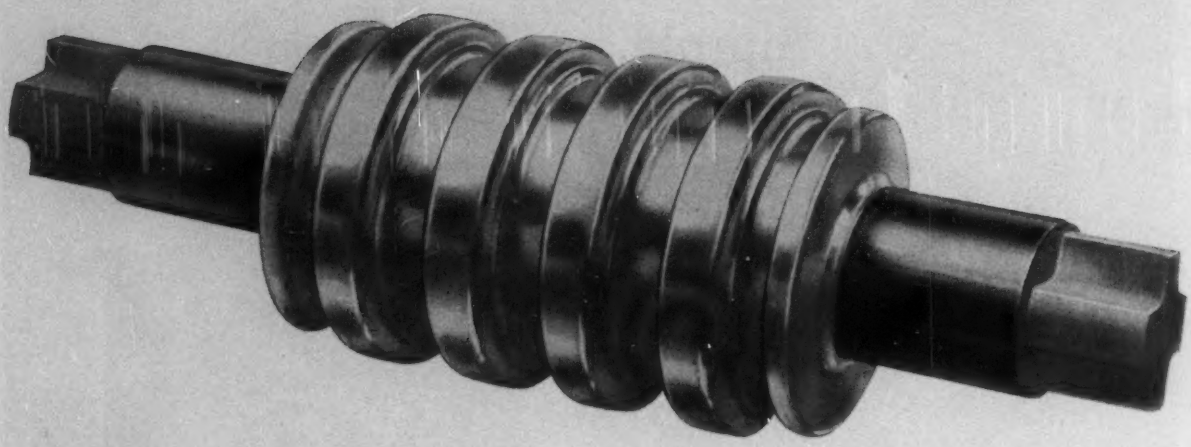

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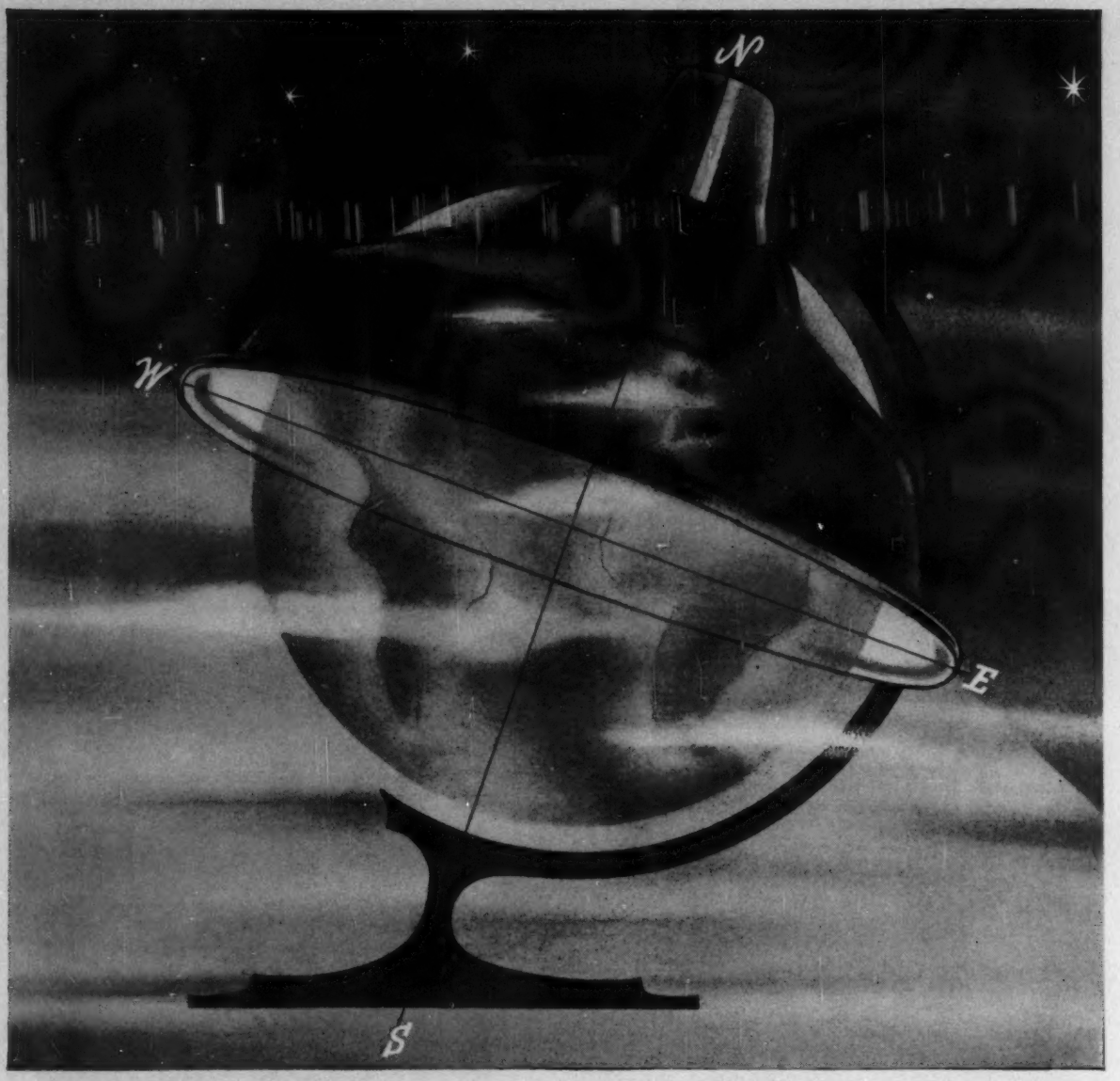

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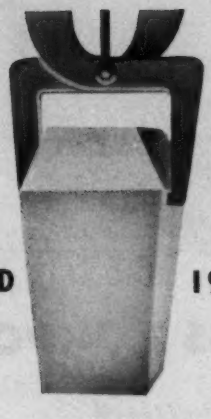

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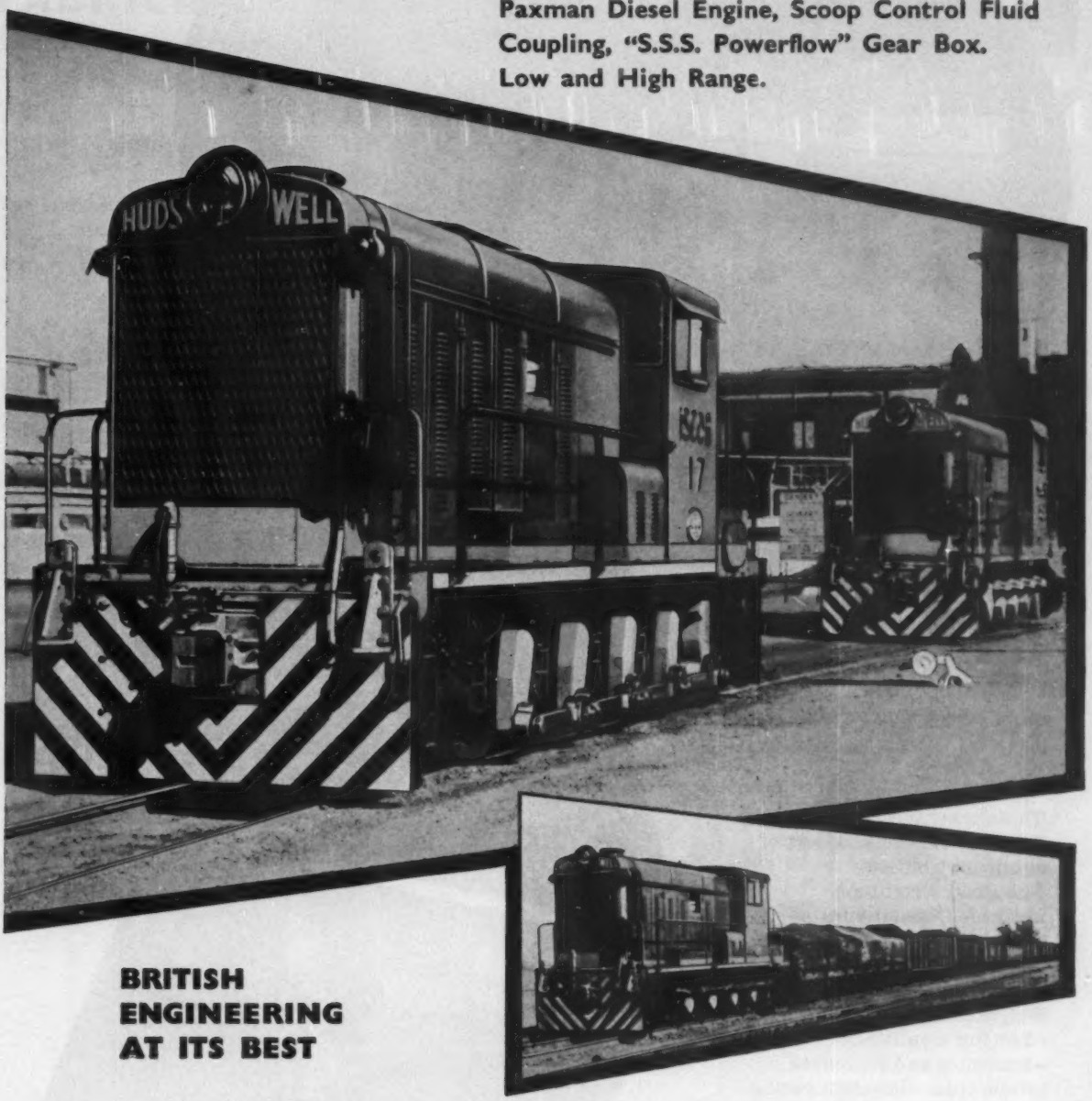

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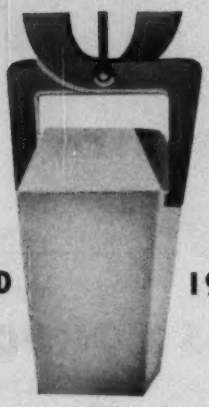

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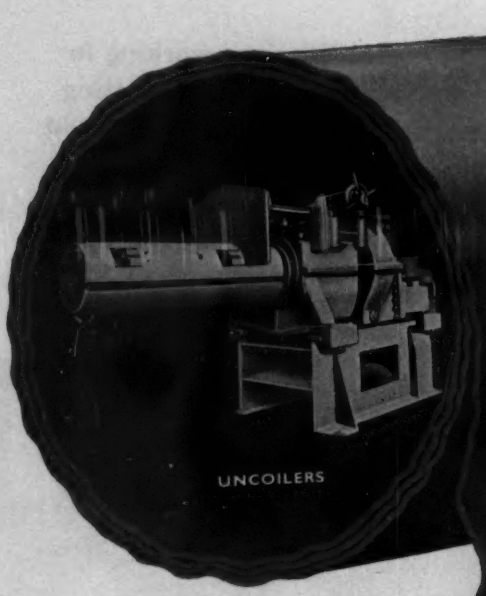

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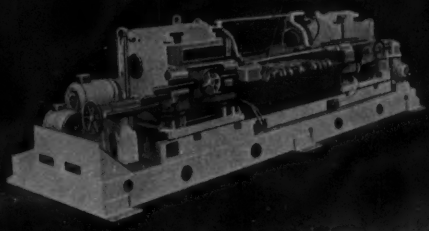

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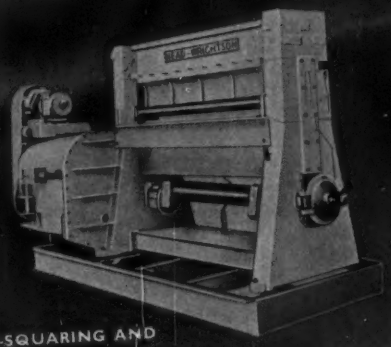

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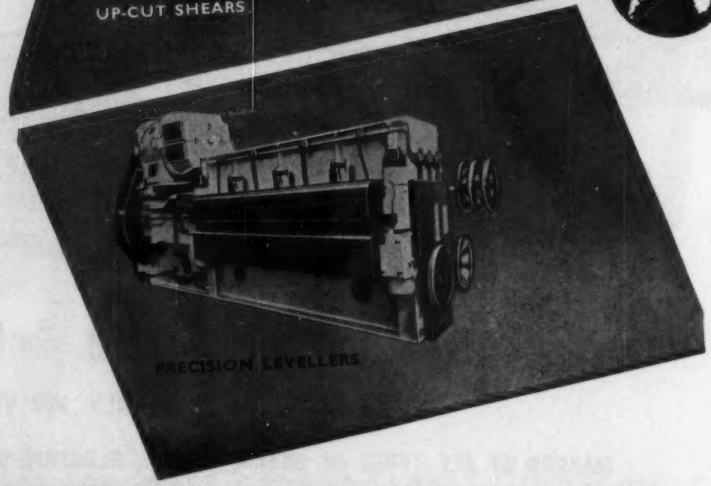

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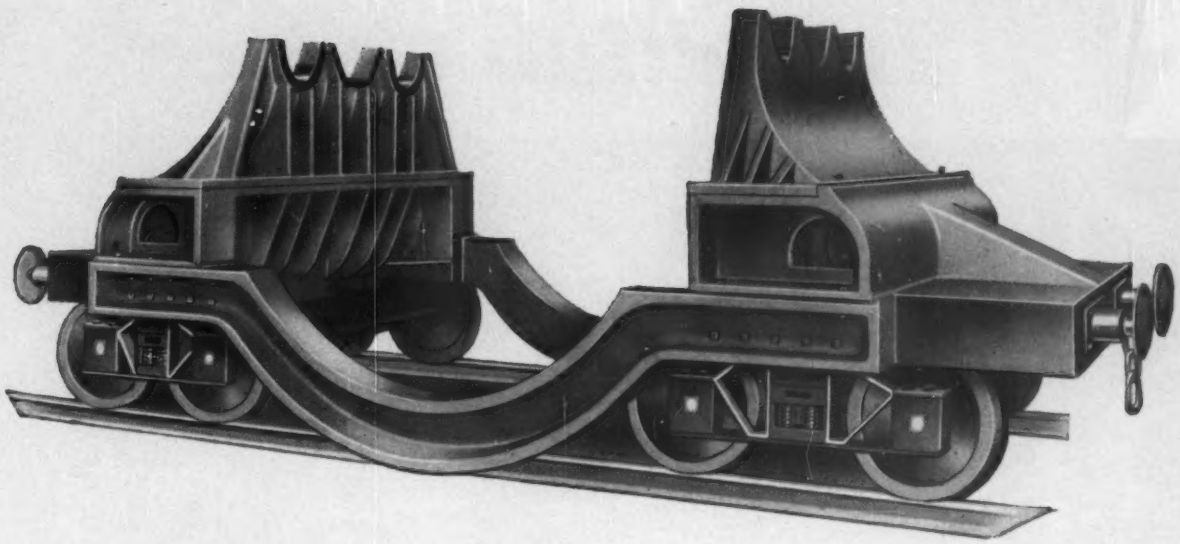

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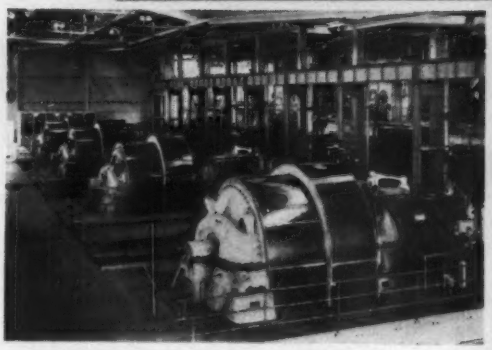

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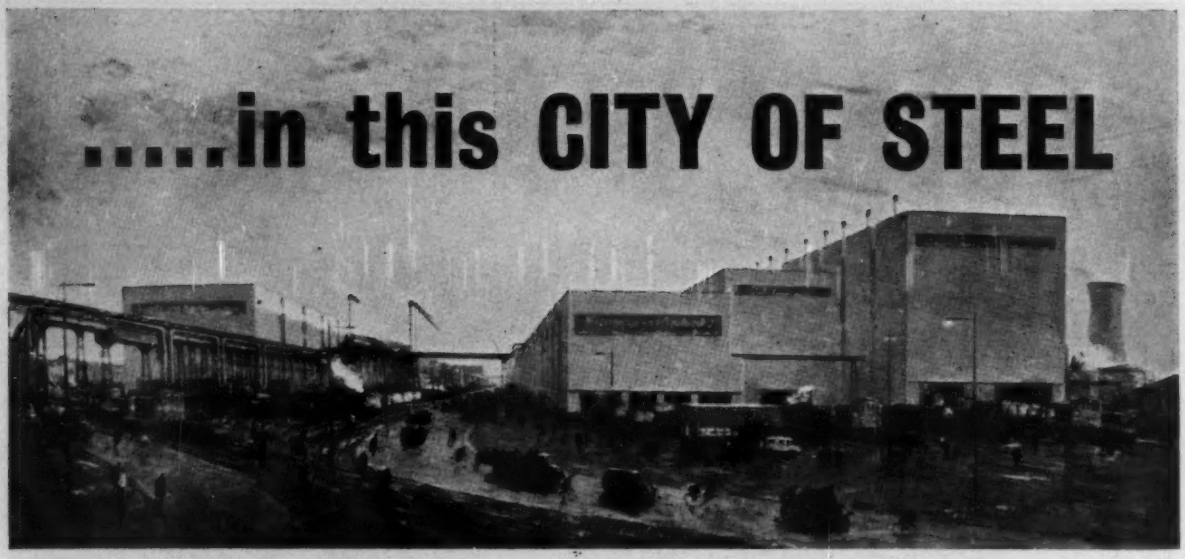

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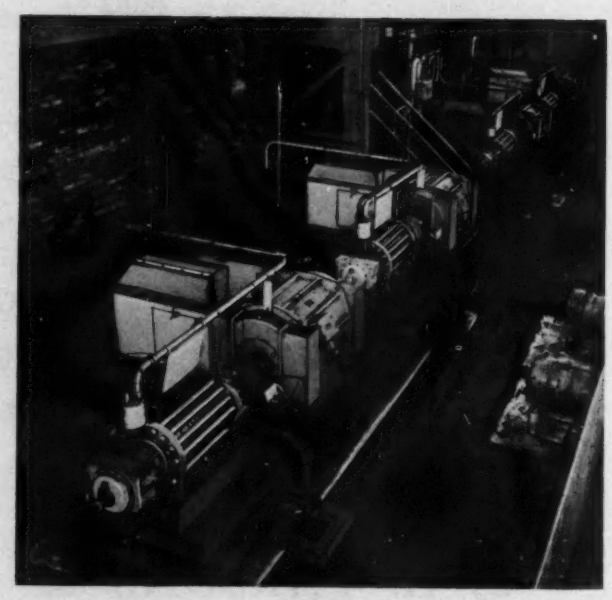

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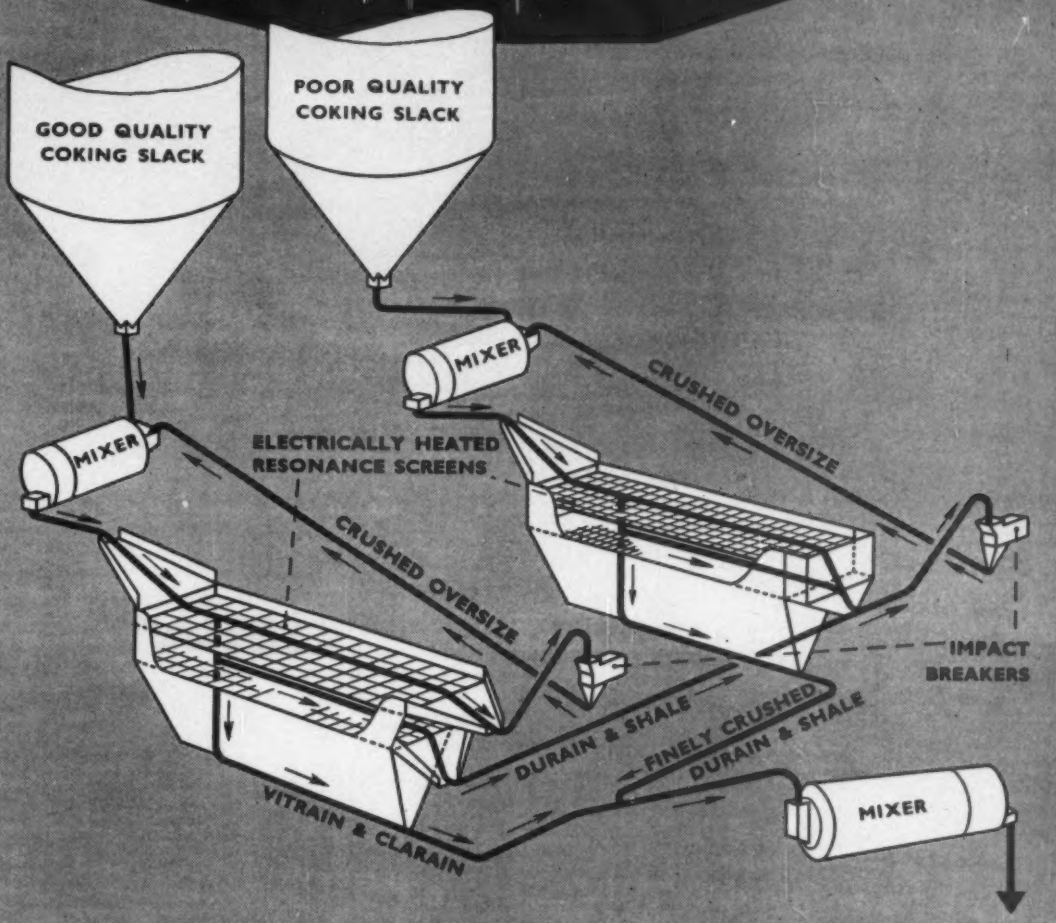

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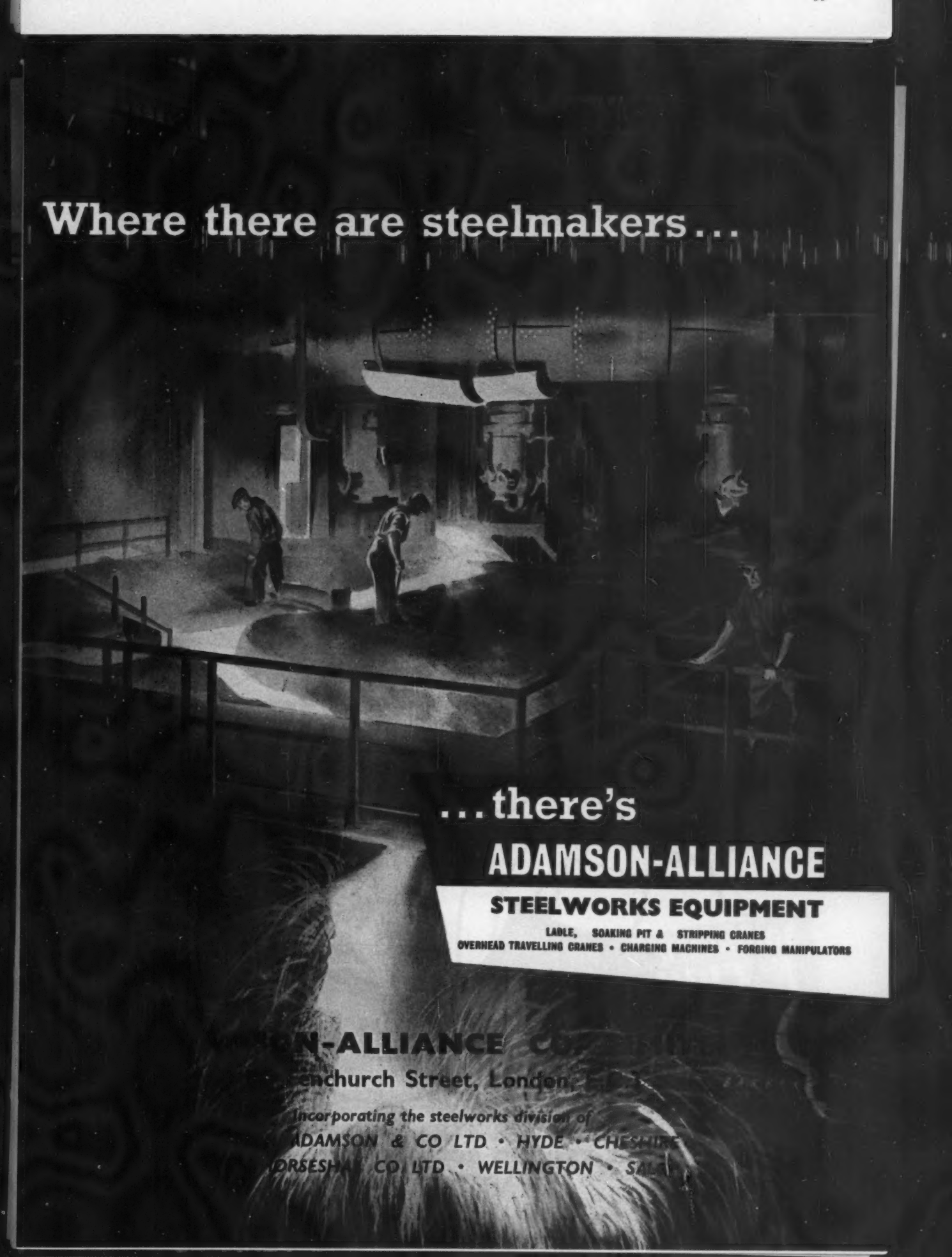

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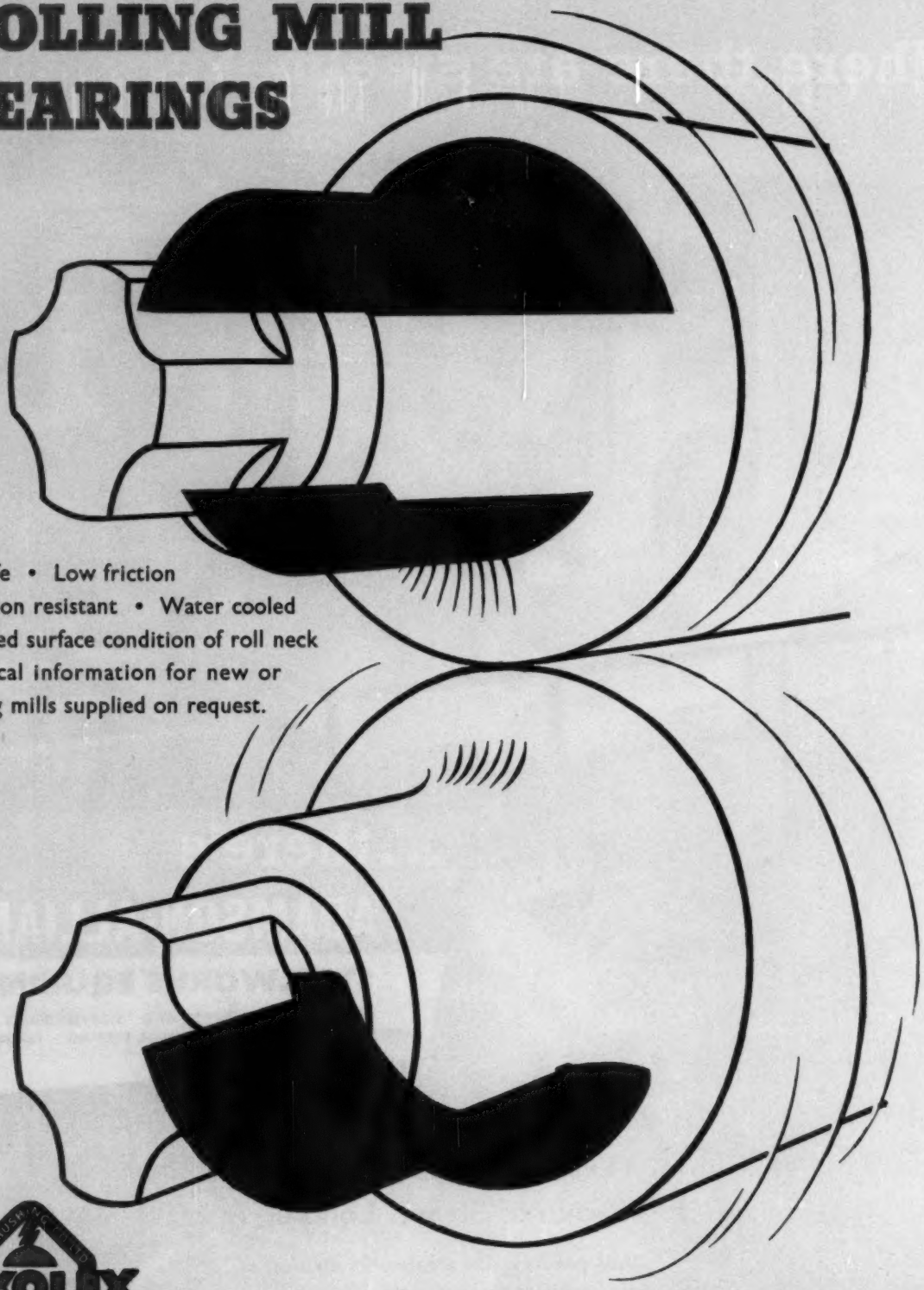

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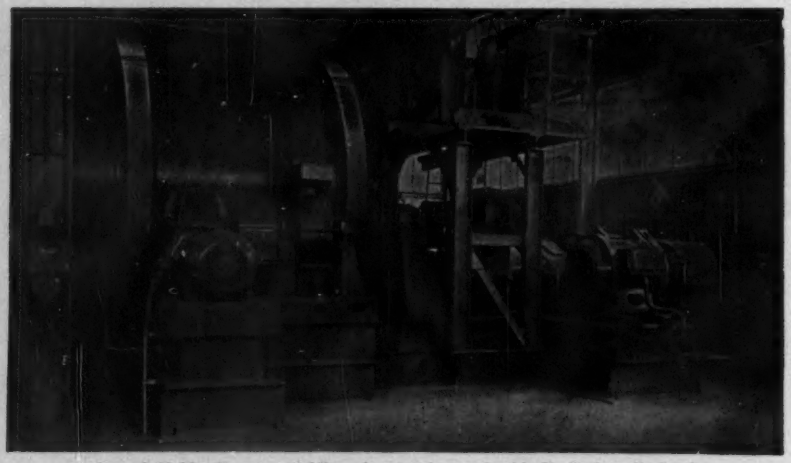

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Journal of The Iron and Steel Institute

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C. R. WHEELER, C.B.E.

CHARLES REGINALD WHEELER has been in the steel industry all his life. He joined Baldwins Ltd. in 1922, and served with them and with their associated companies until the outbreak of the second World War. He became London Manager of the Port Talbot Steel Company and other interests of Baldwins Ltd., a post he held until the formation of Guest Keen Baldwins Iron and Steel Co., Ltd., in 1930. He joined the new company on its formation, later becoming Commercial Manager.

On the outbreak of war in 1939, Mr. Wheeler went with Sir Charles Wright, then Chairman of Guest Keen Baldwins, to the Steel Control, and served under him as Assistant Controller, Raw Materials. In 1943, he headed the U.K. delegation to the Joint Metallurgical Committee in the U.S.A., which considered and reported on alloy steel and alloy conservation. He was appointed Deputy Controller, Raw Materials, in the same year, and became Controller of Iron and Steel two years later. Mr. Wheeler was awarded a C.B.E. by H.M. King George VI in 1946 in recognition of his war services.

In May, 1946, he returned to Guest Keen Baldwins Iron and Steel Co., Ltd. (since renamed Guest Keen Iron and Steel Co., Ltd.) as Joint Managing Director, a post he still occupies. When the Steel Company of Wales Ltd. was formed in 1947, he became a Director and served in that capacity for some years.

Mr. Wheeler has represented the Government on the Steel Committee of the Economic Commission for Europe and the Committee of the Organisation for European Economic Co-operation. He accompanied the late Mr. Ernest Bevin to the Foreign Ministers' Conference in Moscow in 1947. He is a member of the Council and of the Executive Committee of the British Iron and Steel Federation, and as Chairman of B.I.S.C. (Ore) Ltd. has been responsible for buying foreign ore for the steel industry and for the exploration of possible future sources of supply.

Among the other companies of which Mr. Wheeler is a Director are the British Iron and Steel Corporation Ltd., Brymbo Steel Works Ltd., La Compagnie Minière de Conakry, Guest Keen and Nettlefolds Ltd., Guest Keen and Nettlefolds (South Wales) Ltd., G.K.N. Reinforcement Ltd., John Lysaght's Scunthorpe Works Ltd., Ore Carriers Ltd., Mannesmann-Hüttenwerke A.G., and George Wimpey and Co., Ltd. He is a Member of the Court of Governors of the University College of South Wales and Monmouthshire and was High Sheriff for the County of Glamorgan in 1955. In 1953 he received the Légion d'Honneur (Chevalier).

Rowing has always been a great interest of Mr. Wheeler's, and he is a member of Leander and of the London Rowing Club, being on the Committee of the latter. He is Chairman of the Lake Padarn Committee of the 1958 Empire Games. He is also Joint Master of the Old Berkeley Beagles.

Mr. Wheeler joined The Iron and Steel Institute in 1927, and became a Member of Council in 1946. Six years later he was elected a Vice-President, and at the Annual General Meeting in May this year he took office as President for 1958–1959. He is an Honorary President of the Journées Internationales de Sidérurgie, which is being held in Belgium and Luxembourg this month at the same time as the Institute's Special Meeting.

C. R. Wheeler, C.B.E.

President, 1958–1959

PRESIDENTIAL ADDRESS

Raw Material Supplies and the Future Development of the Iron and Steel Industry

By

C. R. Wheeler, C.B.E.

INTRODUCTION

THE RECENT GROWTH of world steel production has been spectacular (*see* Fig. 1). In the last ten years, annual world steel production has about doubled—an increase of approximately 150 million ingot tons. In other words, during the last decade the steel industry has undergone roughly the same expansion as in the preceding period of almost a century since the inception of Bessemer and open-hearth steel-making. Authoritative estimates of the future demand for steel prepared by organizations in various parts of the world are all in general agreement that the requirements of steel will continue to increase substantially in the future.

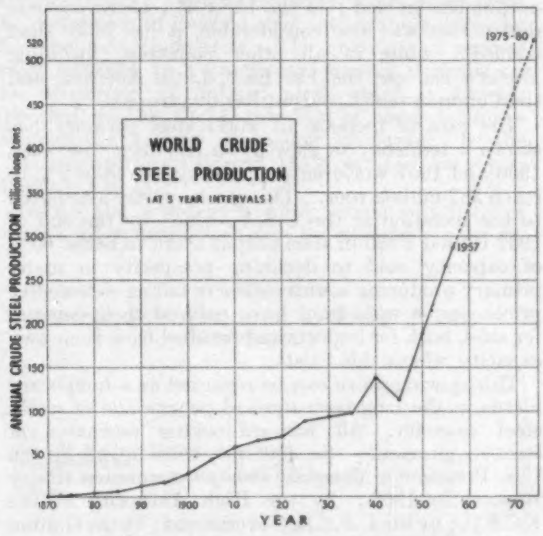

Fig. 1—Graph of world steel production

The basic expansionary factors affecting steel demand, the growth of populations and the universal striving for higher standards of living (which nowadays are directly related to greater steel consumption), are ever present. It is true that recent experience is that the rate of increase in world steel production has shown a tendency to slow down ; the stage has been reached in the western world where the large investment in steel capacity made since the war has caught up with demand, particularly in the U.S.A. and to a lesser extent in Western Europe and elsewhere.

The post-war expansion was induced by the simultaneous growth of steel demand for investment in manufacturing industry, as all countries strove to expand their industrial capacity ; for investment in raw materials to support the greater manufacturing capacity ; for defence ; and above all for the durable consumer goods of which the world was starved during the war.

With the completion of the post-war investment programmes and the decline in defence requirements, which in turn have affected the demand for durable consumer goods, some steel capacity has become idle. But the basic expansionary factors—the growth of population and the drive to higher living standards, particularly in the underdeveloped regions—coupled with the era of rapid technological change that the world is surely entering upon, should stimulate the

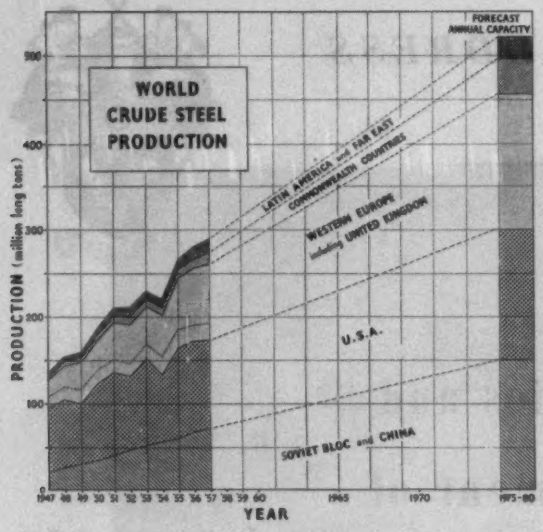

Fig. 2—Graph showing regional growth of steel production since the war and projections to 1975–1980

demand for steel once more. There is no ground to regard the present halt as more than a temporary variation from the basic upward trend, although it may well be that the general levels of future steel production which have been forecast may be achieved at dates which differ from current predictions.

The continued rapid growth in world steel production will demand very considerably increased supplies of the basic raw materials—scrap, ore, and fuel. The probable nature and availability of these essential raw materials are problems which are being given considerable attention by the steel industries of the world. A period of vigorous growth also provides unusual opportunities for the practical application of new processes or major modifications to existing methods.

It is perhaps opportune to consider what effect the raw material supplies likely to be available to the rapidly expanding steel industry may have on the broad pattern of future development, and on the selection of processes for new plants. I have taken this as the theme of my Presidential Address, with perhaps a not unnatural emphasis on the iron and steel industry of the United Kingdom.

GROWTH OF WORLD STEEL PRODUCTION

What has encouraged this vigorous expansion of world steel production, and is it likely to continue?

The stimulus to more rapid development of steel capacity derived partly from the war itself, and partly from the drive to industrialization by the less developed countries.

A considerable backlog of demand for steel which had been pent up during the war was released in 1946, both in the steel-producing countries, where a high proportion of output had been devoted to defence purposes for several years, and in the steel-importing areas, which had suffered from considerably restricted supplies throughout the war. In addition, in some major steel-producing areas (particularly in North America) the expansion of industry for war production had created new high levels of income and demand, while in the war-devastated areas the need for steel to meet the requirements of reconstruction and to permit the growth of manufacturing industry to new levels was considerable.

In the steel-hungry importing countries, wartime expenditure overseas by the combatants resulted in the accumulation of currency reserves which these countries were anxious to spend on steel and steel-consuming manufactures to further their economic advancement. At the same time, with their war experience in mind, many of these steel-importing countries resolved to expand their own steel capacity to ensure at least an essential minimum steel supply in periods of world shortage.

The outflow of funds from the U.S.A. in the form of Marshall Aid to Western Europe and Technical Aid to under-developed areas, and from the new monetary institutions set up in the immediate post-war years, provided much of the finance with which to restore and increase steel capacity.

The outbreak of the Korean war in 1950 gave rise to new defence demands, and caused shortages of steel and most raw materials. A large steel expansion programme was initiated in the U.S.A. to meet these new demands on the industry, and in other primary producing countries expansion programmes for ferrous and non-ferrous metals and other commodities were also undertaken. These in turn raised the level of incomes, and consequently of steel requirements, in the raw material producing areas which provided an additional impetus to the expansion of the steel industries of the world.

Figure 2 demonstrates the regional growth of steel production since the war in the various areas of the world. Output in the U.S.A. has grown by a third; in the U.K. by a half; in Western Europe, where much of the steel industry was dislocated by war, output has trebled; in the U.S.S.R., where wartime destruction was also considerable, it has more than trebled; while in all other countries, including Eastern Europe, the Far East, Latin America, and the Commonwealth, output has quadrupled.

The rate of increase in world steel capacity has shown a tendency to slow down recently. Between 1956 and 1957 world output rose by less than 2% to reach 287 million tons. This can be partly attributed to the recession in the U.S.A., which by the end of 1957 caused a fall in steel output there to below 60% of capacity, and to declining prosperity in many primary producing countries where falling commodity prices over a wide front have reduced their demand for steel, both for imports and for steel from their own capacity where this exists.

This slowing-down can be regarded as a temporary hiatus in the long-term upward progression of world steel capacity. All forward-looking estimates of steel requirements—for example, those made by the U.S. President's Materials Policy Commission (Paley Report) in 1952; by the High Authority of the E.C.S.C.; by the U.S.S.R. Government; by the Gordon Commission on "Economic Prospects for Canada";

by the Minister of Iron and Steel, Indian Government for India ; and by the Australian Government—are in accord that their countries' requirements of steel in future will be considerably greater than at the present time.

The establishment of wider areas in which free trade can develop, and the liberalization of world trade in general, should lead to a greater volume of production and interchanges in the world, with a corresponding effect on the demand for steel.

Looking twenty or twenty-five years ahead, it is not impossible that world steel production in a year of normal activity may exceed 500 million ingot tons. This estimate is based on official forecasts where available, and on estimates which take into account recent rates of increase for those regions where no official forecasts have been made. The regional breakdown of this possible future world steel production is shown in Fig. 2, and detailed in Table I.

This increased output of steel will make very much greater demands on supplies of raw materials for steelmaking.

SCRAP SUPPLIES

A quick method of increasing steel production with a minimum of capital expenditure is to use increased quantities of scrap, and it is not surprising that scrap should be in short supply during a period of rapid expansion in world steel production.

The rapid increase of production in the post-war years was aided by the unusually high supply of capital scrap, collected in the war areas, the U.K., the U.S.A., and elsewhere, but these abnormal accumulations of capital scrap have now been depleted.

Scrap for steelmaking is derived from three main sources. Two of the three categories of scrap are produced in direct relation to current steel output and recycled within a relatively short period of time—circulating scrap arising within steelworks, and averaging about a quarter of the tonnage of crude steel produced ; and process scrap which arises from the conversion of finished steel into manufactures by the steel-using industries. The quantity of process scrap returned in a particular country depends on the proportion of finished steel which is directly exported, and on the distribution of home deliveries between the various steel-using industries. In the U.K. process scrap formed 13½% of steel output in 1956 (*see* Fig. 3).

Taking the world as a whole, some two-fifths of current ingot production can be expected to be returned as circulating and process scrap within a relatively short period.

Capital scrap is thrown up by the demolition of ships, buildings, and bridges, the replacement of plant and machinery, and the scrapping of cars, etc. The supply is affected by a number of factors—the input of manufactured products into the economic system in much earlier periods ; the distribution between the different categories of goods, which have very varying lengths of life ; and the current state of trade, which determines the rate at which obsolete assets are withdrawn from service.

The changing pattern of consumption towards a higher proportion of capital assets of shorter life (e.g. more cars, refrigerators, and steel furniture) may be expected eventually and gradually to have its effect in speeding the return of capital scrap to steelworks.

The rate of scrapping of machinery, ships, and other capital equipment declines in periods of active trade. It is often worthwhile at such times to retain obsolete equipment in production, and also the labour needed for dismantling may not be readily available. The supply of capital scrap thus tends to follow a cyclical pattern, being least plentiful when it is needed most, so greatly aggravating the fluctuations in the demand for steelmaking pig iron. If it is possible to maintain reasonably stable employment, the flow of capital scrap is likely to be more even than in the past.

It is probable that the supply of capital scrap in the immediate future will be most affected by the low rates of activity in the steel industry during the 1930's. Since the war the U.K.'s supply of home-bought capital scrap has varied between 1½ and 2½ million tons a year, forming a decreasing proportion of ingot production.

The U.K. is, however, in the special position of major exporters of finished steel and of manufactures made from steel. In 1957 some 8½ million ingot tons or two-fifths of U.K. steel output was exported as

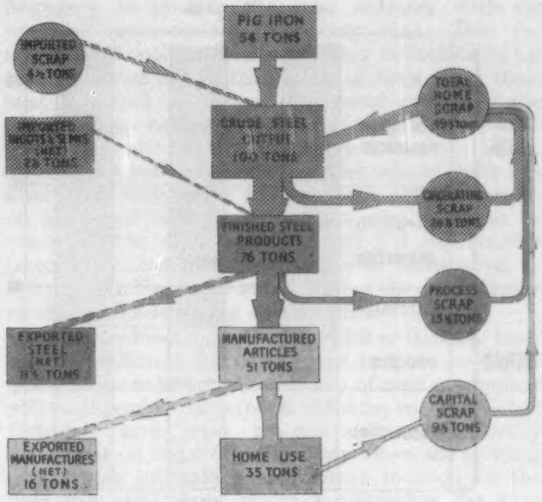

Fig. 3—Diagram showing U.K. scrap cycle for 1956

Table I

FORECAST OF WORLD ANNUAL STEEL PRODUCTION

	million ingot tons
U.S.A.	150
U.S.S.R., Eastern Europe, and China	150
Commonwealth	40
Western Europe (including United Kingdom)	155
Others	25
	520

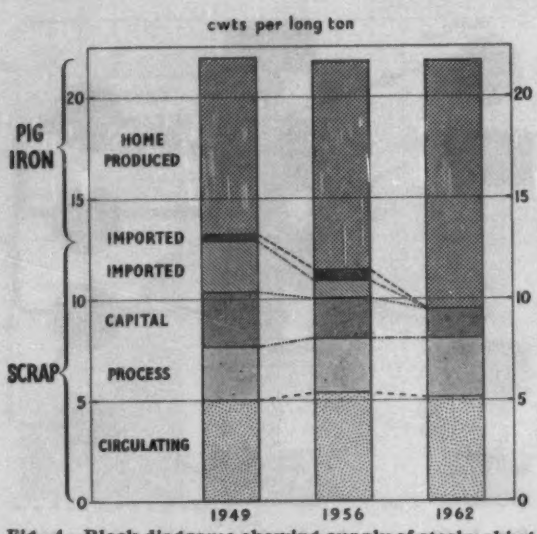

Fig. 4—Block diagrams showing supply of steelmaking scrap in the U.K. for 1949–1956 and estimated 1962

direct or indirect exports, compared with a third of steel output in 1948 ; i.e. the U.K. has lost and will continue to lose a large (and probably increasing) proportion of her potential scrap supply through exports. Where formerly scrap arising in overseas regions might have been returned to the U.K., to an increasing extent these supplies are forming an integral part of the raw-material resources for new steel industries being set up overseas. A rather special illustration has been the experience of the U.S.A., where during and immediately after the war exports of steel and steel manufactures were at exceptionally high levels. This conspired to make scrap supplies a real problem for the first time in the history of the American steel industry, although the position has since been restored.

The lag in capital scrap supplies during a period of fast-increasing steel production has already affected the balance between steelmaking raw materials, and the major steel industries of the world have moved to meet the reduction in the availability of scrap (*see* Fig. 4). In the U.K., the U.S.A., E.C.S.C. countries, and the U.S.S.R., increments in steel capacity have been accompanied by a more than proportionate increase in blast-furnace capacity.

By 1962, for example, the increase in blast-furnace capacity planned by the U.K. is expected to be adequate not only to meet the requirements of additional steel production but also to render the industry independent of imports of scrap and pig iron.

The increasing dependence on pig iron may to some extent be selective and accentuated at individual plants. Steelmaking processes, such as the electric furnace process, which consume high proportions of scrap can only continue to expand without a change of practice if there is a corresponding increase in the proportion of pig iron used in other processes.

This growing reliance on pig iron as a steelmaking raw material emphasizes the importance of still more efficient iron production, and leads to a consideration of possible alternatives to the orthodox blast-furnace.

IRON PRODUCTION

Considerable effort has been and is being devoted throughout the world to developing alternatives to the orthodox blast-furnace for the reduction of iron from iron ore. This has been stimulated by the desire to develop processes that are independent of or much less dependent on metallurgical coke, that can utilize materials which without pretreatment are unsuitable for the orthodox blast-furnace, or that hold promise for producing an end product containing less impurities than traditional pig iron. In general it appears that these alternatives will have only limited use within the foreseeable future, and it is unlikely that there will be any serious rival to the orthodox blast-furnace as a mass producer of iron for steelmaking. Further increases in furnace size are to be expected but revolutionary changes in the design of the blast-furnace are unlikely.

The electric blast-furnace is well established in certain parts of the world, but its application is limited to conditions where the availability and cost of electric power are specially favourable compared with metallurgical coke. Much has been heard of the low-shaft furnace in recent years but, owing to its relatively low thermal efficiency, its application would appear to be limited to locations where metallurgical coke or electric power are not readily available, or where the furnace can be used as a supplementary unit at orthodox blast-furnace plants to deal with ore and coke fines.

A variety of other processes, several involving rotating kilns, such as the Krupp–Renn process, have been developed, but here too their application would seem to be economically limited to special local conditions.

Processes such as the Wiberg–Söderfors for the production of sponge iron have proved to be technically practicable, but they are only economically feasible where supplies of pure ore are available for the production of high-quality melting stock for steelmaking at a cost which compares with the price of scrap, i.e. at places remote from scrap supplies or at times of prolonged and acute scrap shortage.

Several direct-reduction processes using an external source of heat and hydrogen or hydrogen-rich gas as the reducing agent are in various stages of development. An example is the H-iron process of the Hydrocarbon Research Inc. and the Bethlehem Steel Co., in which hydrogen gas at high pressure is passed through fine iron ore of high purity at relatively low temperatures to produce metallic iron powder.

A process for the production of steel without the intervention of an intermediate stage of ironmaking has long been the goal of steel metallurgists, and it is possible that developments such as the Cyclosteel process of the British Iron and Steel Research Association may have long-term possibilities. Fundamentally, however, such processes would seem to be dependent on a natural or artificial source of pure iron oxide. In this age of rapid development of atomic energy and man-made earth satellites it would be rash to prophesy that this problem will prove intractable, but a practical solution seems to be sufficiently far removed to offer no serious rivalry to the orthodox blast-furnace in the foreseeable future.

The outputs which can be obtained from units of these alternative ironmaking processes are small in relation to the fully developed potential of the modern blast-furnace, and the high tonnages of production required at integrated steel plants suggest that the adoption of alternative processes would require a multiplicity of units and considerable capital expenditure. It must not be overlooked that the output of many existing blast-furnaces can be very substantially increased, often at relatively small capital cost, by improvement in operating techniques, the further development of high top pressure, the use of higher blast temperatures, and the possible oxygen-enrichment of the blast by oxygen or steam. Further improvements in output and economies in operating costs at the blast-furnace can be achieved by more extensive application of ore preparation and sintering, although this may require substantial capital investment.

Even at locations where the supply of coking coal is inadequate to support the required expansion of production, the economics of the alternative ironmaking processes have to be compared with those of processes for the manufacture of metallurgical quality coke largely or entirely from non-coking coals.

Past President James Mitchell reviewed this general question of possible alternatives to the blast-furnace in his Presidential Address in 1953 and summarized the position admirably " . . . the blast-furnace is likely to retain its pre-eminence as a producer of metallic iron from the naturally occurring and available materials until such time as ore treatment processes provide a product which is virtually pure oxide ".

The attention of the more advanced iron and steelmaking countries is, therefore, being devoted mainly to the conservation of coking coal resources by the development of methods for the production of suitable quality metallurgical coke from an increasing proportion of non-coking coals and to the reduction in the coke consumption per ton of iron. Twenty years hence the world steel industry may require an additional 120 million tons of metallurgical coke a year to support the required increase in pig-iron production ; perhaps nearly a third of this could be met by the universal application of modern coke-saving techniques to existing production.

SUPPLY OF METALLURGICAL COKE

Within the foreseeable future there would appear to be no practical alternative to the use of coke in the large-scale production of pig iron. The increase in demand for coke can be reduced by the further substantial improvements which are possible in blast-furnace practice, but the increasing dependence of an expanding iron and steel industry on coals for coke production would seem inevitable.

In some countries there is no lack of coal of suitable quality, but the requisite supplies for the steel industry may be difficult to obtain because of the rival claims of other users of coal. In the U.K., for example, nearly half the output of deep-mined coal could be used for coking purposes, although at present less than a quarter is so used. In such circumstances some major redistribution of coal supplies may be necessary to provide the steel industry with its essential requirements of coking coal. This reappraisal of national fuel policy may be facilitated by the increasing use in the future of fuels other than coal, e.g. fuel oil, imported natural gas, methane drained from coalfields, and electricity from nuclear power stations. The steel industry itself can make an important contribution, for in steelmaking there are alternative fuels to gas and gas coals. Conversion to oil firing not only makes process coal available to other users to whom it is essential, but also enables larger quantities of coke-oven gas to be supplied to the gas grid, thus reducing the call of the gas industry on the available coking coal supplies.

Other steelmaking countries which so far have been just self-sufficient for coking coal supplies may find that further substantial expansion of steel production will be dependent on imports of coking coal, while less fortunate areas may become still more heavily dependent on imports. This may affect the existing competitive advantage and future location of the industry, particularly where the industry has been based on cheap, home-produced, low-grade ore. The alternative of importing more high-grade (and therefore fuel-saving) foreign ore may have to be faced.

The practice of blending a proportion of less satisfactory coking coals with coals of higher coking properties is increasing, and undoubtedly will be extended in the future.

Work on the production of metallurgical coke entirely or largely from coals of poor coking properties has been in progress for many years, and several different approaches have been adopted. The Burstlein process, for example, employs a system of selective grinding and screening to provide a homogeneous coke-oven charge of controlled particle size and petrographic distribution.

Other processes depend on two or more stages of treatment of the coal. Coals of poor coking properties are carbonized at low temperatures to produce a char, which is subsequently incorporated in a blend with coking coals or with high-volatile coals of poor coking quality, as in the Marienau process developed for the Lorraine coals.

In other cases bituminous additions are made to the blend containing weakly coking coals or low-temperature semi-coke. The bituminous additions are generally limited economically to the amount yielded by the high-temperature carbonization, although the Japanese Bojuntan process produces the bituminous addition by a separate heat-treatment of a mixture of coal and tar.

In developments such as the Baumco and the National Fuels processes, non-coking coals or blends of coal and sometimes semi-coke with or without a binding agent are briquetted and then carbonized in vertical retorts.

Yet another approach in utilizing coals with inferior coking properties has been the production of iron-coke, in which fine ore and flue dust are mixed with coal before coking.

It is probable that in regions where supplies of coking coal are limited and expensive, processes such as those outlined, or further development of them, may find greater application than hitherto in the

GROWTH OF SINTER PRODUCTION IN THE U.K.
ANNUAL PRODUCTION OF SINTER million long tons
YEAR
1938 1940 1942 1944 1946 1948 1950 1952 1954 1956 1958 1960 1962

Fig. 5—Graph showing U.K. sinter production, projected to 1962

utilization of high proportions of coals of inferior coking quality.

ORE PREPARATION AND AGGLOMERATION

The need to conserve coking coal resources and to obtain maximum production of pig iron from the available metallurgical coke may be expected to lead to rapid acceleration in the present trend towards the more extensive use of ore preparation and agglomerating techniques. The resulting advantages of increased production and reduced coke consumption at the blast-furnaces are only achieved at the expense of considerable capital expenditure on ancillary plant (to some extent counterbalanced by reduced expenditure on coke-oven capacity), but this must be faced if the additional iron production envisaged for the future is to be obtained.

Sintering also serves to make available for ironmaking supplies of fine ore and concentrates which would otherwise be an unacceptable burden for the blast-furnace. Viewed from this aspect, it is probable that sintering capacity in Britain, and perhaps in some other parts of the world, is temporarily ahead of the availability of fine ores and concentrates, but the production of fine ores and concentrates may well rise substantially in the future.

The need for increased ore-preparation and sintering capacity must be reviewed against the perhaps more important background of the considerable revision that has taken place since the war in the generally accepted technical and economic optimum proportion of sinter which should be used in ironmaking. Fifteen years ago a commonly held view was that a burden containing about one-third sinter represented the optimum conditions. Today the advantages of a completely prepared and sized burden are widely recognized, and experience in this country and abroad, particularly in Sweden and Russia, has drawn attention to the remarkable outputs and low coke consumption—approaching the theoretical—which can be obtained with 100% sinter practice on ores which range from lean to rich. In Russia, where operations are perhaps judged more by purely technical performance than by the economic standards of the West, 85% sinter practice is already common. It is by no means certain, however, that 100% sinter practice is universally desirable. For example, where rich and easily reduced lump ore is available, the capital and operating costs of preparation may outweigh the operating advantages, if any, at the blast-furnace.

Interesting developments in sintering practice itself are taking place, and production on an increasing scale of self-fluxing sinters holds special promise.

The steel industries of the world are showing a growing appreciation of the importance of burden preparation. The British industry, for example, has progressed considerably and within the next four years a further substantial expansion in sinter capacity will be completed (*see* Fig. 5). It is estimated that by 1962 sinter production will reach at least 18 million tons a year—double the present production, and a seven-fold increase since the war.

Similar trends are evident in other countries also. In the E.C.S.C. countries production of sinter rose from 14·6 million tons in 1952 to 18·2 million in 1956, and the High Authority estimate that potential annual capacity will double by 1960 to 40 million tons.

In Russia sinter-plant capacity is to be increased to give 100% sinter availability at the larger integrated plants, and a general average of 86% of the ore burden. Sinter capacity is expected to reach 73 million tons by 1960, as compared with a production of 40 million in 1956.

Sinter capacity in the U.S.A. has already risen from 38 million tons in 1955 to over 60 million tons, and further developments are planned.

INCREASING DEPENDENCE ON IMPORTED ORE SUPPLIES

The growing dependence on pig iron naturally focuses attention on iron-ore supplies. The largest and richest additional sources of iron ore are now generally in regions remote from the main steelmaking areas, and the major steel industries of the world are therefore becoming rapidly more dependent on imported ore.

For example, in 1956 home ore accounted for 56½% by weight of the ore used for ironmaking in the U.K. By 1962 a substantial increase has been planned in the tonnage of home ore mined, but even so it is expected that the proportion by weight of home ore used in ironmaking will be little more than 50%.

Home ore is low in iron content—it averages about half that of imported ore—and it is clear that there must be severe physical limitation to the increase in output of home ore which can be sustained over a long period. Overburden is steadily increasing, and there will have to be a growing resort to underground mining. Even a substantial increase beyond 1962 in the long-term production of home ore to the limit which some experts forecast of about 30 million tons

would only be sufficient to maintain an increase in steel production of about 4 million tons, which at the present rate represents rather less than four years' growth in the U.K. steel production.

In terms of iron content, about 37½% of our present iron production is based on home ore, and it is estimated that the proportion will fall to about 33% by 1962. Expressed in another way, about three-quarters of the increased iron production which is planned between now and 1962 will be based on imported ore (*see* Fig. 6).

The E.C.S.C. countries are faced with a similar situation. Compared with 1955 it is envisaged that ore imports will need to be doubled by 1965 and more than trebled by 1975. In terms of iron content, the proportion of pig-iron production based on imported ore will increase from about one-third in 1955 to well over half in 1975. Again virtually the whole of the increased pig-iron production will be based on imported ore.

In terms of iron content, the industry of the U.S.A. is already dependent on imported ore for a third of its pig-iron production. Estimates presented by James C. O. Harris of the U.S. Bureau of Mines indicate that over the next twenty years there will be little change from the present annual iron-ore production of about 100 million tons, so that almost the whole of the planned increase in iron production will have to be based on imports, primarily from Canada and Venezuela. By 1975 the U.S.A. may well be dependent on imported ore for more than half its pig-iron production.

In contrast, the U.S.S.R., China, India, and the newly developing South American industries would seem to have adequate indigenous iron ore resources for foreseeable developments.

The rate at which the major western steel industries can continue to expand in the long term would, however, appear to be largely dependent on the supplies of imported ore which can be made available. The location of new developments will also be affected, and there will be an increasing trend towards the construction of new plants at coastal sites, e.g. as in America and new Continental developments at Bremen, Dunkerque, and Savona. To secure a regular and increased supply of ore imports, the steel industries of the world are having to extend their interests to financial participation in new and existing mines overseas, the construction of special-purpose ore carriers, and the provision of bulk unloading facilities and stocking terminals. The U.K. industry has already made considerable progress in this direction.

The quality of ores likely to be available may also affect the choice of steelmaking process for new developments.

QUALITY OF FUTURE IMPORTED ORE SUPPLIES

The bulk of the additional ore supplies which are in prospect are low in phosphorus, and the position may well arise where the demand for imported phosphoric ores may equal or even exceed the expected supply. This will have its effect on steelmaking at existing works as well as on the selection of process for new plants.

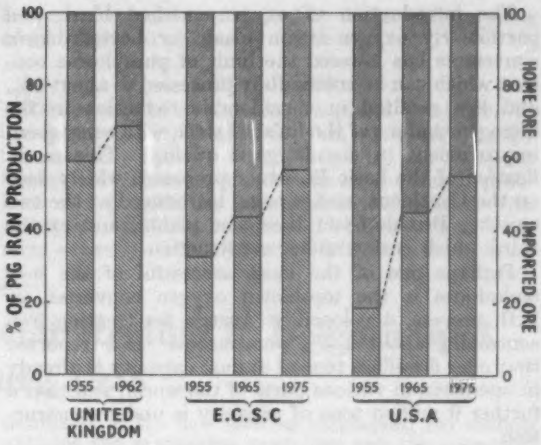

Fig. 6—Block diagrams illustrating the increasing dependence on imported ore of the U.K., the E.C.S.C., and the U.S. industries

In the traditional development of basic steelmaking it has been accepted that the basic Bessemer process should be adopted for irons with a phosphorus content in excess of about 1·7%, and fixed open-hearth furnaces for iron of less than about 0·5% phosphorus. The electric-arc furnace has found application primarily as a scrap melting unit for the production of higher-grade steels. Flexibility to deal with varying proportions of scrap and with irons covering a range of phosphorus contents has been achieved nationally, and at some individual plants, by a suitable balance of the different steelmaking processes.

Differences in the quality of iron which could be made from locally available raw materials has influenced the broad pattern of development. The Continental countries, for example, are preponderantly dependent on the basic Bessemer process, while in the U.S.A. low-phosphorus iron has led to the widespread adoption of the open-hearth process. In Britain also the open-hearth furnace is preponderant, although much of the iron available for steelmaking has been in the range of 1–1·3% phosphorus. It was for such conditions that the large tilting furnaces were developed. Dilution with scrap has been employed to deal with iron of intermediate phosphorus content, but even so a high metallurgical load has been imposed on the open-hearth furnaces in the United Kingdom and this has adversely affected productivity.

The advent of relatively cheap tonnage oxygen has opened up interesting new possibilities, for it has encouraged the development of pre-refining techniques and of new oxygen-blown converter processes capable of dealing with irons of intermediate and low phosphorus content.

The pre-refining of blast-furnace iron with oxygen to remove the silicon is already widely practised, while the extension of pre-refining to cover the removal of phosphorus offers the possibility of further improving the productivity and flexibility of established steelmaking processes, such as the fixed open-hearth and electric-arc furnaces.

The introduction of oxygen-enriched blast, and particularly oxygen–steam blast, for bottom-blown converters has lowered the limit of phosphorus content which can be successfully processed to about 1%, and has resulted in considerable reduction in the nitrogen content of the finished steel, with consequent improvement in metallurgical quality. This modification of the basic Bessemer process is widely used on the Continent, and is being introduced at the two existing British basic Bessemer plants, and at the third which is now under construction.

Perhaps one of the most successful of the new techniques is the top-blown oxygen converter, or L.D. process, developed in Austria for treating iron containing about 0·2% phosphorus. It is reported that over 5 million tons of annual capacity is already in operation in various parts of the world, and that a further 9 million tons of capacity is under construction.

Two oxygen-blown rotary converter processes—the Kaldo and the Rotor—have been developed recently in Sweden and Germany, and although they have not yet reached the same stage of application as the top-blown converter process they appear to have the special merit of being capable of dealing with irons ranging up to 2% in phosphorus content. All these processes produce steel low in nitrogen and hence overcome what has hitherto been regarded for many purposes as an inherent disadvantage of converter steel.

Flexibility in steelmaking practice to deal with a range of phosphorus contents is an important requirement, not only because of the present trend towards an increased supply of low-phosphorus ores, but also as a safeguard against possible long-term and substantial variations in the phosphorus content of the iron during the probable economic life of a plant. The pendulum is swinging from a surfeit to a relative scarcity of phosphoric ores, but the development in the future of as yet unprospected ore fields may reverse this trend.

Considerable attention has been given to extending the range of both the oxygen–steam bottom-blown converter and the top-blown oxygen converter. Work on oxygen–steam bottom-blowing of *Stahleisen* indicates that iron containing as little as 0·2% phosphorus may be successfully converted, while it now appears that top-blown oxygen converters may well be adapted to deal directly with irons containing up to 1% or more of phosphorus.

Recent progress and experience in the development of various oxygen converter processes is to be reviewed at the forthcoming Special Meeting of the Institute in Belgium and Luxembourg, and British steelmakers are looking forward to this meeting with particular interest.

The trend towards an increased proportion of low-phosphorus ores will have a varying effect on existing steelmaking practice in different countries. For example, it need have little effect on the American industry, where the phosphorus content at many works is in the range of 0·15–0·35%, but it is of considerable importance to the Continental industries, which are based substantially on the basic Bessemer process.

In Britain it may be that phosphoric ores likely to be available to this country in the future would just be sufficient to support the plants based on imported ore which use basic Bessemer converters or large tilting furnaces. This leads to the possibility that low-phosphorus ores should be reserved for works operating fixed open-hearth furnaces to produce steelmaking iron approximating to *Stahleisen* in composition. This in turn could lead to a welcome increase in productivity of existing open-hearth furnaces, particularly when allied with the use of oxygen for refining.

The irons likely to be available for new developments will be much lower in phosphorus than those to which we have been accustomed in Britain, perhaps ranging up to 0·4% or 0·5% at plants based on mixed home and imported ore practice. This suggests that completely new integrated plants, based entirely or substantially on imported ore and using a high proportion of pig iron, may employ some form of oxygen-blown converter process capable of dealing with irons of intermediate and low phosphorus contents, with perhaps a considerable expansion in the use of electric-arc furnaces for scrap melting and duplexing.

The rate at which these new developments can be introduced may depend, however, on the availability of capital, and on an adequate return on the large capital expenditure required for new steelworks construction.

FUEL BALANCE

The growing importance of converter processes, the production of higher proportions of pig iron per ton of steel, the trend towards the use of large electric-arc furnaces for bulk steel production, and the possible introduction of continuous casting suggest a radical change in the fuel balance of future steelworks. At integrated plants based on imported ore, large quantities of coke-oven and blast-furnace gas will be available, while converter and electric steelmaking processes will not require gas or oil fuel. A greater proportion of electricity will be generated, which may be economically used by electric-arc furnaces.

The British industry is based so predominantly on the open-hearth process, however, that the introduction of other types of process will inevitably have only a gradual effect on the national position, but the dependence of the industry on fuel oil may tend to decrease.

Ultimately, the generation of relatively cheap electricity from atomic energy may further encourage the use of electric steelmaking. Expert opinion is by no means unanimous as yet, but the supply of cheap nuclear power may well be a possibility in the reasonably near future. For example, Sir Christopher Hinton, Chairman of the Central Electricity Generating Board, recently predicted that nuclear power will be cheaper than conventionally produced power by 1962, provided that the present rate of development of nuclear power stations is maintained and the present trends in coal costs continue. Within twenty-five years, nuclear power may be less than half the cost of conventionally generated power.

Although industrial application of the direct use of atomic energy for process work may well be far removed—some authorities predict that this will be in the next century—the possibility remains of atomic energy, either in the form of cheap electricity or used directly, rendering the industry less dependent on coking-coal and fuel-oil supplies.

This may be of special importance not only to some of the present underdeveloped countries who lack coal supplies, but also to the major steel-producing countries, who may well find that their continued long-term expansion is limited by inadequate supplies of metallurgical coke.

CONCLUSION

This review of raw-material supplies in relation to the future development of the iron and steel industry is necessarily sketchy and incomplete, but I hope it has served to remind us of some of the major problems and possibilities which must be tackled with enterprise and determination if the continued long-term expansion of our great industry is to be secured.

Summaries of Papers for Special Meeting in Belgium and Luxembourg 1958

THE COUNCIL have accepted an invitation from the Presidents of the Centre National de Recherches Métallurgiques, the Groupement des Industries Sidérurgiques Luxembourgeoises, and the Groupement des Hauts Fourneaux et Aciéries Belges to hold a Special Meeting of the Institute in Belgium and Luxembourg from **18th to 28th June, 1958,** at the same time as the Journées Internationales de Sidérurgie, 1958, which are being organized in Belgium and Luxembourg on the occasion of the Brussels World Exhibition.

Joint technical meetings of The Iron and Steel Institute and the Journées Internationales de Sidérurgie will be held at Liège, Luxembourg, and Charleroi. The proceedings will be conducted in English, French, and German, with simultaneous translation facilities available between these three languages.

Preprints of all the papers to be presented at each session will be distributed in advance to those attending. The papers will be printed in their language of origin with a synopsis of each paper in English, French, and German. All the papers to be presented in Liège and Charleroi will be published in due course in their language of origin in the *Revue Universelle des Mines*. All papers to be presented in Luxembourg will be published in due course, in their language of origin, in the *Revue Technique Luxembourgeoise*. Some of the papers will also be published in English in the *Journal* (these are marked * in the list below).

The following are summaries of the papers to be presented at each session.

Section I—LIÈGE

Theme: "New Developments in Steelmaking"

1st and 2nd Sessions:

"CONVERTER PROCESSES"

The Conversion of Pig Iron by Bottom Blowing

By J. DAUBERSY and A. DECKER
(*Centre National de Recherches Métallurgiques, Liège*)

After outlining the problem of the origin of blowing with oxygen-enriched air or with gas mixtures, the authors recapitulate the methods used: blast oxygen-enriched to 30%, mixtures of oxygen and steam in one or several stages, double slagging with sodium carbonate, desulphurization by the classic method or with siphon ladles, desulphurization in the converter with lime low in sulphur. They then summarize the method of operation, including the raw materials and analyses of the products obtained. In this connection, they examine the problem of refractories, and the control of operation by weighing and analysis of the charge and by spectrographic analysis at the end of the heat. They show that basic Bessemer steel is not necessarily more oxidized than steel made by any other process. The hydrogen content of oxygen–steam-blown steels is not higher than that of other steels. Having stated the problem of scrap and the field of usefulness of the new blowing techniques, the authors examine the mechanical properties and the costs, and close by touching on some aspects of the future outlook.

The Refining of Low-phosphorus Pig Iron in the Bottom-blown Converter

By H. KOSMIDER, A. WEYEL, and H. NEUHAUS
(*Klöckner Hüttenwerke Haspe A. G.*)

After showing how much scrap can be melted during refining of pig iron of different phosphorus contents as a function of blast enrichment with oxygen in a converter, the authors report trials on the conversion of low-phosphorus irons by means of oxygen–steam mixtures. A 22 metric ton cast takes 6–8 min and the steel obtained, which is very low in residual elements, is comparable with the best open-hearth steels.

The authors also studied the chemistry of the refining process of iron in the basic converter and in the open-hearth furnace with regard to oxidation, dephosphorization, desulphurization, and the slagging of manganese. They examined the amount of lime used and the quantity of slag produced per metric ton of iron as a function of silicon and phosphorus content. They give evidence for the economic value of a second slag for producing low phosphorus contents.

In the final section they compare the fields of application of the L–D process and the basic Bessemer process with 32% oxygen, oxygen–steam mixture, and ordinary air with reference to the analysis of the iron, the amount of scrap used, and the analysis of the steel. They conclude by examining the productivity of these processes and the question of brown fume.

French Experience with Bottom-blown Converters

By M. ALLARD
(*Institut de Recherches de la Sidérurgie*)

The paper summarizes the work carried out by IRSID to arrive at optimum methods of working for the basic Bessemer process, requiring only modifications or additions to existing installations. These principles may be stated as follows: defining correct profiles for converters fitted with large bottoms to reduce spattering, but in other respects the same, or allowing the treatment of larger tonnages; a desulphurization process with powdered lime which makes it possible to charge the converter with very low-sulphur iron, even where the blast-furnace pig iron is very high in sulphur: injection installations for powdered materials, using special pumps, which minimize the disadvantage of high silicon contents in the iron and increase productivity; and the controlled addition of ore or other materials with the object of obtaining consistently low nitrogen contents.

As a result of these methods, and by means of limited blast enrichment with oxygen (in certain cases at the end of the operation) steel of basic-converter quality can be consistently obtained, starting with basic Bessemer iron of any quality, with a favourable yield and high productivity.

Refining Pig Iron with Oxygen by the Kaldo Process

By Bo Kalling and F. Johansson
(*Stora Kopparbergs Bergslags A.B.*)

The Kaldo process has been in use on a commercial scale at Domnarvet since May, 1956, mainly for the refining of basic Bessemer steel. This process might also be used for the conversion of low-phosphorus pig irons (e.g. hematite irons).

The high rotation velocities and the possibility of varying them make it possible to control the iron content of the slag, since rotation brings about intimate contact between the slag and the metal. The process has an excellent thermal yield and a high yield of iron. The author also examined the problems of fumes and of refractories.

The process makes possible the production of very high quality steels low in sulphur and nitrogen and its use might be extended to make carbon steels without recarburizing. The economic aspects of the process and its commercial value are discussed.

The Rotor Process

By R. Graef and L. von Bogdandy
(*Hüttenwerk Oberhausen A.G.*)

The paper is divided into three sections: metallurgy of the process, method of control, and industrial operation.

The first section deals with the layout of the plant, the movement of the furnace, drives for the machines, and a description of the auxiliary installations. This is followed by a description of the operating technique with two lances, the study of the fumes, the movement of the metal and the slagging agents, and the kinetics of oxygen absorption in the bath. The second section is devoted to the relation between the position of the lances, fume composition, and other measurable quantities which can be automatically controlled. The authors describe the automatic control of the depth of immersion of the lance and the control of the discharge of oxygen by new devices for the measurement of differential pressure. They also describe a new method for bath-temperature measurement. In the last section the results obtained by systems of control on two rotors in service and the degrees of purity obtained are detailed. By choosing a sufficiently large fusion bed, it is possible to produce by this method a steel low in residual elements.

The Production of Pig Iron with 0·5–1·5% Phosphorus by the L–D Process

By H. Trenkler
(*Vereinigte Oesterreichische Eisen- und Stahlwerke A.G.*)

After defining the field of operation of the L–D process and reviewing the trials described in the literature on the refining with pure oxygen of phosphoric irons with over 0·5% phosphorus, and in particular basic Bessemer iron, the paper describes four series of tests on the conversion of irons produced in the electric furnace, starting from forge iron and ferrophosphorus with phosphorus contents between 0·8% and 1·4%.

The principle of the method consists in carrying out the operation with two slags so as to use the second for the first part of the next cast. At the start, the test conditions were somewhat different. They were made up of preliminary additions of scrap, lime, and fluxing materials. After 10 min of blowing, fine ore was added and the converter was tipped. After slagging, fresh quantities of lime and fluxing materials were added. The amount of lime used in the trials varied from 140 to 160 kg per ton of steel; near the end of the first stage the phosphorus content is already below 0·4%. To be able to hold the slag in the converter, the author proposes to use the method of Dofasco at Hamilton (Canada), using a pouring hole provided in the converter wall. In the trials described the slag used for the first period was the standard L–D slag; this gives a reduction of 4–5% in lime consumption.

The paper then examines the productivity of the proposed method and compares it with the Kaldo and Rotor processes. So far as the consumption of refractories is concerned, an increase of the order of 36% must be allowed, corresponding to the longer time of refining of the phosphoric irons compared with the iron usually treated. The comparison from the economic standpoint of 0·3% P irons with those used involves an extra cost of about DM 10·00 per ton for the former.

The author then reports the physical properties of L–D steel. The production of steel starting from phosphoric iron by the process described in this paper is submitted in a second stage to the same conditions as in the normal L–D process. Analyses of the steels obtained are identical.

Owing to these two factors, the properties of the steels can be expected to be the same as those of L–D steels, as the trials carried out have already shown.

Production of Special Steel by the L–D Process

By O. Cuscoleca and H. Rösner
(*Oesterreichisch Alpine Montangesellschaft*)

The object of this paper is to record, from work done at Donawitz, the state of development of production by the L–D process of some interesting grades of steel from the points of view of manufacture and properties.

The first section concerns carbon steels, the production of which is carried out by recarburization of the metal after refining or by stopping conversion at the desired carbon content. The former method has not been tried experimentally at Donawitz. Since the start, Donawitz has attempted to arrest refining at the carbon content required. Production of rail steel was the main aim. The manganese content lies between 0·7% and 0·9%, and the carbon is about 0·6%. Finally, it is necessary to add ferro-manganese to the converter. The time for refining is actually the clue to the stepping of the operation. Thanks to rapid analysis (4 min), 93·6% of the casts for rail production fell within the desired limits of 0·50–0·55% C and 0·90–1·10% Mn.

For production of carbon steels with low manganese contents, it is advisable to run off the slag when opportunity offers. The authors show the value of the L–D process for the production of different grades of steel.

The authors also show how the technique can be developed for alloy steels of various kinds and give practical examples.

A New Refining Process for Pig Iron Using Pure Oxygen and Lime Powder

By B. Trentini and M. Allard
(*Institut de Recherches de la Sidérurgie*)

The new refining process described by the authors was first tried in a 3-ton converter, after verifying several factors on a 300-kg scale. The authors have now progressed to industrial-scale trials on a 20-ton basic Bessemer converter with the normal bottom replaced with a solid bottom. The process consists of injection over the molten iron by means of an oxygen lance carrying finely-divided lime in suspension; the lime concentration varies with the nature of the iron and the stage of the operation it has arrived at. The technique of the operation takes place in three stages in large converters:

(*a*) After charging of iron and ore, which acts as a cooling agent, two-thirds of the oxygen and lime needed for complete refining is blown in, the concentration of lime in the oxygen varying, particularly in relation to the amount of silicon in the iron charged. The fluid slag obtained, rich in P_2O_5, is in part removed, the bath being then at a temperature around 1600° C

(*b*) Further blowing with oxygen and lime with corresponding additions of ore and further deslagging

(*c*) Final blowing, giving an iron-rich slag in the case of the production of ultra-mild steel; this slag can be kept in the converter.

The authors describe the chemical and thermal bases of the operation, characterized by displacement of dephosphorization during carbon removal according to chemical properties of the steels produced in respect of phosphorus, nitrogen, and sulphur.

JOURNÉES INTERNATIONALES DE SIDÉRURGIE 1958 and SPECIAL MEETING OF THE IRON AND STEEL INSTITUTE

Honorary Presidents of the Meeting

L. Bouvier

President, Groupement des Industries Sidérurgiques Luxembourgeoises

A. H. Ingen-Housz

Past-President of The Iron and Steel Institute

(Mr. C. R. Wheeler, President of the Institute, whose portrait appears as a frontispiece to this issue, is also an Honorary President of the Meeting)

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Patrons of the Meeting

His Majesty King Baudouin, King of the Belgians

(Honorary Member of The Iron and Steel Institute)

Her Royal Highness Charlotte, Grand Duchess of Luxembourg

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President, Centre National
de Recherches Métallurgiques

P. van der Rest

President, Groupement des
Hauts Fourneaux et Aciéries
Belges

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3rd Session:

"OPEN-HEARTH FURNACE PRACTICE"

The Driving Rate of Open-hearth Furnaces*

By R. W. EVANS and others
(*Steel Company of Wales Ltd.*)

The paper first deals with the advantages and disadvantages of the open-hearth process in relation to increasing competition from pneumatic processes.

During the last sixty years, greater production of open-hearth furnaces has been due more to increase in size than to higher outputs per unit of hearth area. Such large furnaces have their operating disadvantages and are costly to build compared with plant for equivalent output by pneumatic processes. Increasing the driving rate of the open-hearth furnace would improve its competitive position in relation to the newer processes which have been boosted by the advent of cheap oxygen.

Further sections of the report deal with certain aspects of increasing the driving rate, including papers dealing with increased fuel rates and use of basic refractories, the use of oxygen for decarburization, the use of oxygen for flame enrichment, and research into factors affecting the driving rate.

Basic Open-hearth Steelmaking in the U.S.A.*

By M. W. LIGHTNER and D. L. MCBRIDE
(*United States Steel Corporation*)

The basic open-hearth process continues to be the fastest growing steelmaking process in the U.S.A. Among reasons contributing to the improvement in productive capacity of the open-hearth process are: extended-hearth furnaces with single uptakes, increased firing rates and greater use of oxygen for combustion, growing use of oxygen injection for decarburization starting immediately after the hot-metal addition, use of continuous waste-gas analysis to control the fuel and air input to the furnace, desulphurization of coke-oven gas and hot metal, improved control of bath temperature, and improved refractories and greater use of the all-basic furnace.

Important technological developments indicate that in the future open-hearth furnaces will be larger, heat times will be shorter, and fuel consumption will continue to be reduced; all of these can be achieved without sacrificing steel quality.

4th Session:

"LARGE ELECTRIC FURNACE PRACTICE"

Results Obtained with a 150-ton Electric Furnace

By G. STASSIN
(*Fabrique de Fer de Charleroi*)

After an introductory note on the production of the Fabrique de Fer de Charleroi, the author describes the general installation of an electric steelplant of which the Lectromelt furnace of 24 ft (7·315 m) hearth diameter is the production unit. The weight of the cast under actual working conditions is 150–165 tons. A magnetic ASEA stirrer is placed below the hearth.

The author goes on with a short description of the furnace and then analyses in detail the course of preparation of a cast. The average duration is about 6 h with a completely solid charge. The operating characteristics and the average furnace campaign make up the latter part of the paper. The consumption of electrodes reaches 5 kg/ton of steel and the power consumption 535 kW/ton with the power factor of the furnace averaging 0·82. For hearth repairs the author suggests a mean consumption of about 4 kg of refractory per ton of steel and for the roof 3·2 kg/ton of steel.

Large Electric-arc Furnace Steelmaking Experience in the U.S.A.*

By A. C. OGAN and D. J. CARNEY
(*United States Steel Corporation*)

This paper presents some current operating data and thinking in the U.S.A. in regard to the use of the electric furnace for production of plain carbon steel ingots. The first section deals with trends in furnace design and equipment, particularly emphasizing the marked trend towards large steelmaking furnaces since World War II. Other structural changes are also mentioned. The second section deals with present practices in the U.S.A. for production of plain carbon ingots, including the use of hot metal. The third section lists a summary of the latest operating statistics from large U.S. furnaces producing solely plain carbon ingots. These data indicate a marked improvement in the past four years. The last section discusses in a general manner the economics of electric-furnaces versus open-hearth furnaces for production of plain carbon ingots.

Section II—LUXEMBOURG

Theme: "New Developments in Ironmaking"

5th Session:

"THE LOW-SHAFT FURNACE"

The Low-shaft Furnace—Experience and Results

By H. MALCOR
(*Institut de Recherches de la Sidérurgie*)

[Summary not available at time of going to press.]

6th Session:

"NEW DIRECT-REDUCTION PROCESSES"

Direct-reduction Processes for Iron Ore

By P. M. CAVANAGH
(*Ontario Research Foundation*)

After defining the basic principles for direct-reduction studies at the Ontario Research Foundation, the author first gives a critical study of the processes that have been developed to the industrial stage: Höganäs, Wiberg–Söderfors, Hojalata y Lamina, and those with rotary kilns. In this last class he specially notes the R.N. and Krupp–Renn processes. Productivity, installation costs, and adoption of new techniques are reviewed.

In the second section, the author studies the direct-reduction processes actually in process of development. In this class he first considers processes using fluidized beds: H-iron, Arthur D. Little, and U.S. Steel Nu-Iron. It is also convenient to note the Madaras and McDowell–Battelle processes.

A paragraph is given to the use of iron sponge as a synthetic scrap. The final section is devoted to recent work of the Ontario Research Foundation in the field of direct reduction. The author describes the two processes studied: the O.R.F. Direct Steel process and Jet Smelting. The first of these consists essentially of the rapid reduction of a bed of ore of high purity on a moving grate, passing through a zone of magnetite oxidation, a zone of ferrous oxide reduction, and a final reduction zone; the slab is then rolled directly and continuously into sheet one-tenth of the original thickness.

Jet smelting consists of treating pulverized ore at a very high temperature with natural gas and oxygen. The magnetite concentrate is entrained in a very hot natural-gas–oxygen flame. The particles break up under the influence of the flash heating and come in contact immediately with a large excess of natural gas in which they are reduced; the stream is then directed vertically downwards and penetrates at great speed into a bath of molten metal and slag.

7th Session:

"RECENT DEVELOPMENTS IN BLAST-FURNACE PRACTICE"

Survey of Modern Blast-furnace Techniques*

By T. P. COLCLOUGH
(*British Iron and Steel Federation*)

The paper reviews the principal lines of development in the modern techniques of blast-furnace practice. A critical analysis is made of the thermal balance in furnaces operating on the same raw materials with unprepared and prepared burdens. For this purpose the smelting

operation is divided into four zones and a comparison is made of the relative amounts of heat generated and utilized in each of the zones. Examination is made of the principles underlying and the improved production to be anticipated from the application of self-fluxing sinter, higher pressure and temperatures of the air blast, and the addition of steam and oxygen to the blast.

Use of Oxygen, Moisture, and High Top Pressure in Blast-furnace Operation

By J. M. STRASSBURGER
(*National Steel Company*)

The different methods which are described in the paper have, during the last seven years, increased the output of pig iron per furnace (27·5% at Weirton Division) while reducing the gross weight of coke used per ton of iron (137 kg per ton of pig iron).

After a preliminary series of diagrams showing the advantage of enriching the fusion zone with ore concentrates, the author goes on to describe three techniques.

The enrichment of the blast with oxygen produces generally an increase in production which is equal to the ratio of oxygen content to that in normal air. Thus, an increase of 4% produces a rise in iron production in the ratio of 25 : 21, or about 19%. The enrichment, on the average, which the central oxygen plant at Weirton makes possible is actually about 1·8% and makes possible easy operation of the furnaces and a small reduction of the coke consumption.

Weirton has found that, in general, oxygen enrichment ought to be accompanied by a high blast humidity. Whilst oxygen enrichment or increase of blast temperature have the effect of narrowing the combustion zones of the tuyeres, it seems that increased humidity tends to widen them, to reduce dead space, and so to increase the size of the annulus through which the gases pass.

Besides oxygenation and corresponding humidification of the blast, Weirton has been able to raise the circulation temperature by means of supplementary humidification.

In each of the cases considered, the author discusses in detail the results obtained. The use of top pressure on two blast-furnaces of the Great Lakes Steel Corporation is offered as a further means of increasing production.

8th Session :
"PREPARATION OF THE BLAST-FURNACE BURDEN"

Preparation of the Blast-Furnace Burden—French Experience

By J. ASTIER
(*Institut de Recherches de la Sidérurgie*)

The author has studied, in the first place, the preparation of the charge by crushing, screening, and agglomeration of the fines as practised in France. The increase in the number of crushing plants is noted since 1945, with the improvement they give in blast-furnace practice. The building of sinter plants is not so far advanced for various reasons. For the latter process, the author describes the operating characteristics of French plants and their differences from that at Appleby-Frodingham. The results of a trial for two months with 100% sinter in a Lorraine furnace (5 m hearth diameter, useful volume 485 m³) are described. The results obtained are remarkable for the coke consumption of 708 kg per ton of iron, dry weight, a blast temperature of 675° C, and a temperature at the throat of 261° C.

In the last part of paper, the author considers the possibilities offered by enrichment of the Lorraine ores by physical means. The possibilities appear interesting for the siliceous quartz ores of the north of the Lorraine basin. They also seem favourable for calcareous ores.

A Programme-Controlled Reduction Test for Blast-furnace Burdens*

By R. LINDER
(*Oxelösunds Järnverks A.B.*)

The literature on the reducibility of iron ores is generally referred to ideal conditions which do not resemble those actually met in the blast-furnace. To arrive at an exact value for the reducibility of an ore, the classical methods of testing should be replaced by others where conditions approach more closely to those in the furnace; the temperature and reducing action of the gas should increase with reduction time as well as the mechanical stressing of the ore.

The paper seeks to establish a relation between the behaviour of the ore in the laboratory and in the blast-furnace. The quality of the ore is characterized by four factors: composition, mechanical strength, reducibility, and resistance to breakup during reduction. As a criterion of reducibility the degree of oxidation of the ore when heated to 1000° C is measured. A formula is stated for the degree of oxidation at the 1000° C level in stack gas in the blast-furnace from the results of the test.

After a detailed explanation of this equation, the paper describes the apparatus used and the method of use. It consists mainly of an electrically heated rotating cell and apparatus for gas generation and analysis. The rotation of the cell is intended to assist mechanically in the reduction of the ore.

The temperature and gas composition vary during the test according to a predetermined scheme. The test finishes when the temperature reaches 1000° C.

To estimate the breakup of the ore during reduction, the amount of fines produced is determined. For Oxelösund and Domnarvet sinters the tests have shown very good agreement between the reducibility determined in this way and blast-furnace indirect reduction.

Experience with Sinter Burden in Swedish Blast-furnaces*

By U. NOTINI
(*Jernkontoret*)

Most Swedish blast-furnaces working with coke are using 100% sinter, and many of them self-fluxing sinter. The paper analyses the results obtained by these processes. Coke consumption might be reduced by 20–25% with sinter because of its improved reducibility, and a fusion zone richer in iron and a higher blast temperature might be obtained. The production of self-fluxing sinter gives a further saving of 10–15%. At the same time, this method leads to a considerable increase of output, amounting to as much as 250% for charcoal furnaces and 100% for others. However, the use of sinter may produce an increased tendency for the charge to hang, leading to slips.

The advantages offered by the use of self-fluxing sinter are so significant that it is worthwhile grinding, concentrating, and sintering the ore, even if beneficiation does not increase the iron in the burden appreciably.

Section III—CHARLEROI

Theme: "Continuous Casting of Steel"

9th Session:
"THEORETICAL CONSIDERATIONS AND EXPERIMENTAL EQUIPMENT"

Continuous Casting at the Centre National de Recherches Métallurgiques—Hainaut

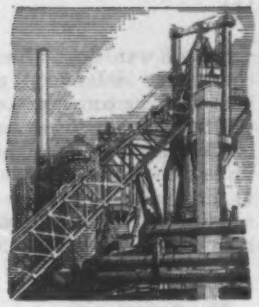
By J. ZAEYTYDT
(*Centre National de Recherches Métallurgiques*)

The author describes the experimental installation of the C.N.R.M. built at the Aciéries et Minières de la Sambre during 1956–1957, the first unit of which went into production in December, 1957. It is intended to test the layout and to study casting conditions for ingots of killed basic Bessemer steel and electric carbon or low-alloy steels from 75 × 75 mm to 125 × 125 mm. A second unit now under construction will serve for the study of the casting of rimming basic Bessemer steel ingots from 120 × 120 mm to 200 × 200 mm and of slabs 120 × 350 mm.

[*Continued on page 168*]

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research



Survey of Modern Blast-furnace Techniques

By T. P. Colclough, C.B.E., D.Sc. (London)

SYNOPSIS

The paper reviews the principal lines of development in the modern techniques of blast-furnace practice. A critical analysis is made of the thermal balance in furnaces operating on the same raw materials with unprepared and prepared burdens. For this purpose the smelting operation is divided into four zones and a comparison is made of the relative amounts of heat generated and utilized in each of the zones. Examination is made of the principles underlying, and the improved production to be anticipated from, the application of self-fluxing sinter, higher pressure and temperatures of the air blast, and the addition of steam and oxygen to the blast.

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IT WILL BE ACCEPTED that, while the efficiency of the blast-furnace as an instrument for the reduction of iron oxides has been for many years of a very high order, thermal efficiency and productivity have left much room for improvement. While considerable progress was made before the war to improve both of these factors, the higher capital expenditure per furnace unit and the increase in cost of labour and of coke in recent years have made it imperative that the rate of production per unit should be raised to the highest economic level and, in particular, that the coke rate should be reduced to as near the theoretical minimum as possible.

The first steps in this direction have been towards the building of larger furnaces which, by virtue of their increased volume, gave larger outputs per day and thereby reduced operating wages costs, and also led to a small but significant reduction in the coke rate. Increased rates of production were also sought by the installation of larger and more powerful turbo-blowers to increase the volume and pressure of the air blown. This trend was soon found to have definite limits, because (*a*) the combustion of coke in the tuyere area is limited to an annular zone round the circumference of the hearth and (*b*) with excessive volumes of air blown, the velocity of the gases in the stack led to flue-dust losses, which proved both uneconomical as regards cost and presented grave difficulties in the disposal and utilization of the flue dust.

The modern developments are all tending towards a reduction in the thermal requirements of the operation and a more effective use of the space available within the furnace.

BASIS OF MODERN DEVELOPMENTS

The fundamentals of modern developments are based on the experimental work of S. P. Kinney,[1] in the U.S.A. in 1927, and confirmed later by Bone and his colleagues[2] in 1937 in the U.K., on the flow of gases in the blast-furnace stack; the work of Furnas[3] on the permeability of stock columns with varying size of particles; and observations made in the U.K.[4] on the heat penetration and reduction of pieces of ore during their passage down the stack of the blast-furnace.

The report of Kinney and his colleagues indicated that the movement of the gases and of the stock in the blast-furnace stack were far from uniform and that, in practice, not more than about 30% of the furnace stack was effective. This condition was proved to arise from the variation in size of the pieces of ore, leading to segregation of large ore and fine dust with corresponding variations in permeability of the stock column. This, in turn, led to channelling of the furnace gases up the centre of the stack and/or in an annular zone near the stack walls. As a result, the gases escaped before effective use could be made of their ' sensible ' heat and of their intrinsic reducing power. On the other hand, descending ore reached the high-temperature and bosh zones in an unheated condition and demanded the consumption of carbon for their direct reduction.

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Dr. Colclough is Technical Adviser to the British Iron and Steel Federation.

In pre-war days the standard practice was to charge the different types of ore from individual bins and, in consequence, the burden charged into the furnace varied according to the particular type of ore being charged. This inevitably led to variation in chemical qualities, as well as physical properties, in different parts of the furnace stack. Under such conditions it was practically impossible to achieve regularity and certainty of furnace performance.

Ore Preparation

The first step towards modern practice has therefore been to secure uniformity of burden composition and regularity of sizing in the ore pieces. It is now accepted that all ore used in the furnaces should be crushed to a maximum size varying from 2 to 4 in. (50 to 100 mm), according to the type of ore, and that all ore below $\frac{3}{8}$ in. (10 mm) should be screened out from the crushed ore. No material entering the blast-furnace should be of less than this $\frac{3}{8}$ in. (10 mm) size and, in consequence, all the fine ore, whether natural or arising from the crushing operation, should be agglomerated by sintering before being charged into the blast-furnace. Further, all the ore used should be thoroughly mixed either by ' bedding ' or other suitable means to give a uniform composition before charging.

In the early stages of development, the sintering operation was confined to the agglomeration of the ore fines only, but the extensive work carried out by Elliot of Appleby-Frodingham in the U.K., at Domnarvet in Sweden, and in the Urals, has demonstrated the advantages of crushing the whole of the ore, irrespective of size, down to a maximum of $\frac{3}{8}$ in. (10 mm) and sintering the whole of the burden.

The essential feature of modern practice is this complete preparation of the ore, and this operation furnishes the basis for all the secondary developments now taking place. The method to be adopted to secure this complete preparation of the burden and the benefits to be derived from varying proportions of sinter in the charge have been so adequately dealt with in papers published in recent years[5] that no further treatment of this aspect is necessary at present.

Before considering the further developments, it may be of advantage to examine in some detail a comparison between good standard practice, prewar (Practice *A*), and the results achieved by furnaces incorporating all, or most, of the recent developments (Practice *B*). Details of the operation are given in Appendix A.

In both cases the furnace is operating on an ore mixture of 58% Fe with the same coke (85% C) and with slag of the same composition. In standard practice (*A*), the ore is charged into the furnace in the as-delivered condition with the necessary additions of limestone and magnesian carbonate. The air blast is taken as normal atmospheric air, with average moisture content (3·5 grains/ft³), preheated to 600° C (1100° F) which is fairly common practice.

In the modern practice (*B*), the trend is to operate on a two-component charge—self-fluxing sinter and coke. The whole ore supply is crushed, mixed with the carbonates necessary to form the slag, and sintered to give self-fluxing sinter. The only limestone charged raw into the furnace is the amount required to flux the ash of the coke. The air blast is preheated to 800° C (1472° F) and steam is added to give a moisture content of 11 grains/ft³.

The substantial increase in the rate of production and the fall in coke rate to be achieved are already well known, but the principles involved are perhaps not equally clear. Essentially, the blast-furnace is a thermal machine, and a comparison of the thermal requirements per ton of iron made by the two practices is given in Table I. The following observations may be made:

(*a*) Apart from changes in the state of oxidation of the ore during sintering, the heat required for the heating and reduction of the ore and for the sensible heat of the liquid metal will be the same in both practices—8·3 million B.t.u.

(*b*) The heat requirements of the slag are markedly different. In the first instance, the slag for practice *A* will be about 1100 lb, compared with 1000 lb for practice *B*, owing to the differential coke rate. In addition, the moisture content and volatile constituents of the ore are removed in

Table I

HEAT REQUIREMENTS IN BLAST-FURNACE: COMPARISON OF TYPICAL PRACTICES

(Per ton of 2240 lb)

	Practice A Unprepared Burden			Practice B 100 % Sinter	
Heat Required per ton of Metal	**Heat of Reaction B.t.u./lb**	**No. of lb**	**B.t.u. × 10³**	**No. of lb**	**B.t.u. × 10³**
A. Metal					
Reduction of:					
Fe from Fe_2O_3	3191	2091	6672·4		
Si ,, SiO_2	12,176	17·9	217·9		
Mn ,, MnO	3158	22·4	70·7		
P ,, P_2O_5	10,843	14·5	157·2		
			7118·2		7118·2
Decomposition of phosphate	925·5	72·5	67·1		
Sensible heat of metal			1142·0		1209·1
Total for Metal			8327·3		8327·3
B. Slag					
Decomposition of:					
$CaCO_3$	769	805	619·0	135	103·8
$MgCO_3$	551	92	50·7	...	...
[CO_2 liberated	402·4 lb or 3460 ft³			59·4 lb or 510 ft³]	
Reduction of CO_2	1595	241·4	385·0	25·6	40·8
Sensible heat	750	1100	825·0	1000	750·0
Total for Slag			1879·7		894·6
C. Water					
Evaporation	1151	185	213·0	75	86·3
Decomposition	5810	43·25	251·3	88	511·3
Total for Water			464·3		597·6
D. Sensible Heat of Gas					
Gas	6·84 (at 220° C)	122,000 ft³	834·9	79,500 ft³ (4·7 at 150° C)	370·0
Water vapour	8·0	4000 ft³	32·0	2315 ft³	12·3
Total			866·9		382·3
E. Heat Losses, etc.	(4·7%)		864·2	(4·5%)	477·9
Total Heat Requirement			12,102·4		10,679·7

the sintering operation. Much more important is the benefit to be derived from the incorporation of the fluxes in the sinter mix. In the example quoted, the heat required to decompose the carbonates is about 0·67 million B.t.u. in practice *A*, compared with 0·1 million B.t.u. in modern practice *B*. Further, the $CaCO_3$ charged is decomposed in the temperature range 800–1000° C, and at this temperature the CO_2 must be reduced by solid carbon to give at least the same CO/CO_2 ratio as the final blast-furnace gas. This reaction is endothermic and the heat absorbed in practice *A* is 385,000 B.t.u. compared with 41,000 B.t.u. for practice *B*. The total heat requirement for practice *A* is approximately 1 million B.t.u. higher than for practice *B*, and the coke consumed for the CO_2 reduction is about 77 lb, compared with 8 lb for practice *B*.

(*c*) The heat required for the water content of the system is higher in practice *B*. The water carried into the stack by the burden and coke is greater in practice *A* than in *B*, but with the addition of steam to the air blast in the modern practice there is an increase in the heat absorbed for its decomposition at the tuyeres.

(*d*) The heat carried away as 'sensible heat' by the blast-furnace gas also shows a significant difference. With the completely prepared burden the volume of the gas per ton of iron is considerably smaller than with the unprepared burden, and in general passes out at a lower temperature. It is estimated that the sensible heat of the gas with practice *B* will show a reduction of 0·48 million B.t.u. compared with practice *A*.

To summarize, the heat requirement per ton of iron with modern practice *B* is about 1·4 million B.t.u., or 11·7% less than with good unprepared burden practice. This reduction of heat requirement, while significant, is not adequate to account for the wide difference in performance and practicularly in coke rate, and an examination must be made of the sources of heat generation.

Heat Generation

The outstanding difference between the two practices arises from the more effective use made of the intrinsic heat value of the coke burnt. Table II summarizes the heat balance for the two practices. The significant features of the heat requirement have been dealt with already. The important factors on the heat generation side are the decrease in the weight of carbon consumed and the increase in the quantity of heat produced per pound of carbon.

Table II
HEAT BALANCE
Per ton of Pig Iron (2240 lb)

	Practice A: Unprepared Burden		Practice B: Prepared Burden
	B.t.u. × 10^3		B.t.u. × 10^3
Heat required:			
Metal	8327·3		8327·3
Slag	1879·7		894·6
Water-evaporation	213·0		86·3
Water-decomposition	251·3		511·3
Sensible heat of gas	866·9		382·3
Losses, etc.	564·2		477·9
Total	12,102·4		10,679·7
Heat generated:			
Combustion of:			
C to CO_2—369·2 lb	5371·9	423·6 lb	6163·5
C to CO—1136·8 lb	4945·0	636·3 lb	2767·5
H_2 to H_2O—1·2 lb	62·5	3·91 lb	203·5
Sensible heat:			
(Blast temperature	600° C		800° C)
Air—86,500 ft³	1701·4	56,000 ft³	1484·0
Water vapour—910 ft³	21·6	1850 ft³	61·0
Total heat	12,102·4		10,679·5

In the unprepared burden the coke rate is 17·5 cwt (1666 lb carbon) as against 12·2 cwt of coke (1161 lb carbon) with the prepared burden—a fall of 30%, corresponding to an increase in production of 43%.

This reduction is brought about by the greater proportion of CO gas used in the stack for the reduction of the iron oxides. In the unprepared burden only about 25% of the carbon burnt is burnt to CO_2, while in the prepared burden the proportion is raised to 40%. The heat generated per pound of carbon used for combustion rises from 6815 to 8430 B.t.u.

The reasons for this increase of efficiency may be found in a closer examination of the operation of a blast-furnace.

Zones of Reaction

For convenience, the blast-furnace operation may be divided into four temperature zones in which the action (chemical and physical) has definitely different characteristics. These zones may be taken as:

(1) 15–450° C
(2) 450–800° C
(3) 800–1000° C
(4) 1000–1500° C.

In zone 1, practically no chemical changes occur unless the ore is of carbonate type, and the thermal requirements are limited to the evaporation of the water in the charge and the sensible heat of the coke and burden up to the temperature of 450° C. In this zone no heat is generated and the whole of the thermal work is effected by the sensible heat of the ascending gases.

In zone 4 (the bosh and tuyere zones) with the temperature range 1000–1500° C, the chemical changes should be confined to the reduction of SiO_2, MnO, and P_2O_5, and the thermal requirements to providing the heat needed for these reactions and for raising the sensible heat to the temperature level (say, 1500° C) necessary for liquid metal and slag.

Heat is generated in this zone by the combustion of carbon, from the coke charged, by the oxygen of the air, and some heat is absorbed by the decomposition of the water in the blast. Further heat is supplied by the sensible heat of the preheated blast.

It is important to note that at the prevailing temperature it is not possible for CO_2 or H_2O vapour to exist in the presence of carbon. As a result, the heat generated by the combustion of carbon is limited to 4350 B.t.u. per lb of carbon consumed, or only 30% of the total heat value of the carbon.

In zone 3 (800–1000° C) the primary reaction is the reduction of the basic carbonates of the fluxes and the reduction of the CO_2 released to CO, because in this temperature range the proportion of CO_2 which can exist in the presence of carbon is very low. Both these reactions are endothermic and, as indicated above, the weight of raw carbonates charged has an

Table III

HEAT GENERATION AND USE BY TEMPERATURE ZONE

	Practice A		Practice B	
	Generated	Used	Generated	Used
	10^3 B.t.u.			
(1) Below 450° C	Nil	778 (7·0%)	Nil	651 (6·3%)
(2) 450–800° C	3828 (31·6%)	4191 (37·2%)	4524 (42·4%)	4640 (45·0%)
(3) 800–1000° C	1286 (10·6%)	4307 (38·3%)	979 (9·2%)	2920 (28·3%)
(4) 1000–1500° C	6988 (57·7%)	1959 (17·4%)	5176 (48·4%)	2086 (20·3%)
Total	12,102	11,235	10,679	10,297

important bearing on the heat requirements, particularly in this zone. During its passage through this temperature range, it is to be expected that the reduction of the iron oxide to metal will be completed. Practically the whole of the work to be done in this range can only be effected by the reaction $FeO + C \rightarrow CO$ and, here again, the heat released by the combustion of the carbon will be only 30% of the full intrinsic heat value. The amount of reduction to be effected, and therefore the carbon consumed in this zone, will be entirely dependent upon the amount of unreduced oxide of iron entering the zone.

Zone 2 (450–800° C) is therefore the critical and most important zone. Below 450° C, little or no reduction of iron oxide can occur; over 800° C, reduction in general must be at the expense of solid carbon which is oxidized to CO; in the range 450–800° C, the iron oxide can be reduced to metal by CO gas, with the double benefit that, while no solid carbon or coke is required, the CO formed in the lower reaches of the furnace is enabled to release the remaining 70% of its intrinsic heat value by its oxidation to CO_2.

This reaction is limited by two factors:

(*a*) The equilibrium between CO, CO_2, and C, which gives a ratio of CO/CO_2 of unity at 500° C

(*b*) The physical factors of gas/solid contact and time.

Since under all conditions hitherto practised there is always an excess of CO present in the stack, the real limiting factor is the gas/solid contact. Theoretically, it is possible to utilize the CO in the ascending stack gases for the complete reduction of the oxide, provided that the necessary physical conditions are established. This reduction is facilitated by any steps which improve the uniformity of distribution of the ascending gases and avoid channelling, increase the permeability of the ore, raise the reducing power of the gas (by increasing the percentage of CO and/or H_2), or increase the relative time of contact by reducing the volume and therefore the velocity of the ascending gases. It is in this zone that the value of ore preparation and sintering in promoting these necessary conditions exerts its dominant effect and the more completely the sintering operation enables this solid/gas contact and time element to be improved, the more nearly is the equilibrium value of CO/CO_2 attained.

In order to visualize more clearly the differences between the two practices and the reasons for the benefit which is derived from the preparation and sintering of the burden, a rough analysis of the heat supply and requirement and the composition and sensible heat of the ascending gases is given in Appendixes *C–F* and is summarized in Table III. While this analysis is only approximate and may require amendment in detail, it is sufficient to give a broad assessment of the underlying principles. The summary indicates clearly a number of important features:

(i) With the unprepared burden, 68% of the total heat made available is generated in the zones above 800° C, where the carbon predominantly burns to CO only, compared with 57·6% in the prepared burden

(ii) In the prepared burden, 42·4% of the total heat required is supplied by the oxidation of CO to CO_2 in the stack (zone 2), compared with 31·6% in the unprepared burden

(iii) With the prepared burden, 63% of the iron oxide is reduced by CO or H_2 at temperatures below 800° C, compared with 56% in the unprepared burden, in spite of larger volumes of CO available.

To summarize, it will be accepted that the benefits derived from the preparation and sintering of the burden arise from the reduction in the thermal load on the furnace, the more uniform distribution of gas flow in the stack stimulating improved gas/solid contact, and an increase in the proportion of oxide reduction in the lower temperature zones by CO instead of by carbon. All these factors tend towards lower coke rates and increased production. In addition to these direct benefits, the preparation of the burden makes possible further developments in blast-furnace technique.

RECENT DEVELOPMENTS

Higher Operating Pressures

The use of higher blast pressures and of higher pressures within the furnace had its origin in the demand for increased iron production from existing furnaces. It is established that the rate of production of a furnace depends upon the rate at which carbon is burnt at the tuyeres and this, in turn, is dependent upon the rate of supply of oxygen in the air blast.

With increased rate of blowing, the velocity of the gases in the furnace stack must increase proportionately, and the point was soon reached at which the flue-dust losses became economically prohibitive, owing to the high throat velocities. It is clear that this effect can be counterbalanced if the pressure

Table IV
EFFECT OF HIGHER BLAST TEMPERATURES

	Unprepared Burden			Prepared Burden	
	10^3 B.t.u.				
Per ton of Iron					
Coke rate, lb	1960			1366	
Carbon rate, lb	1666			1161	
Carbon burnt at tuyeres, lb	1176			800·5	
Air blown, ft³	86,500			56,000	
Moisture					
grains/ft³	3·5			11·0	
weight/lb	43·25			88·0	
Temperature of blast, °C	600	800	1000	800	1000
Heat generated at tuyeres	4864·3	4864·3	4864·3	2971	2971·0
Sensible heat of blast	1723·3	2321·8	2952·0	1544	1963·6
Total heat available	6587·6	7186·1	7816·3	4515	4934·6
Increase	...	598·5	1228·7	...	419·6
Carbon at tuyeres to generate 6587·6 × 10^3 B.t.u., lb.	1176	1078	991	800·5	732·5
Decrease in C	...	98	185	...	68
Decrease in coke rate, %	...	5·88	11·1	...	5·86

within the furnace is increased in the inverse ratio of the volumes of free air blown, because the actual volume and therefore the velocity of the furnace gases can thereby be maintained at a constant value.

It has been found in practice that by increase of the pressure at the furnace throat to about 10 lb/in² the rate of production can be raised by about 6% and, at the same time, there is a marked reduction in the flue-dust losses. Alternatively, if the furnace is operated at the same free air volume with increased pressures, the residence time of the gas in the furnace stack is increased. This tends towards a higher degree of efficiency in the reduction of iron oxide by the CO of the gas, with a corresponding lowering of the coke rate and higher production with constant volume blowing.

This principle of higher operating pressures can therefore be usefully employed to reduce flue-dust losses and either increase production with no appreciable change in the coke rate, or to reduce the coke rate with a small increase of production, or an intermediate stage between the two.

Higher Blast Temperatures

The universal fine cleaning of the blast-furnace gas in modern plants and the development of hot blast stoves of high efficiency have made possible the provision of much higher temperatures in the air blast supplied to the furnaces. The supply of additional heat as ' sensible ' heat obviously reduces the quantity of heat which must be supplied by the combustion of carbon and thereby must reduce the coke consumption per ton of iron. The relation between blast temperature and carbon rate is not linear and the effect of higher temperatures, beneficial or otherwise, must vary according to the particular conditions of both coke rate and temperature.

As a first approximation, an examination is made in Table IV of the thermal conditions in the tuyere zone of the typical furnace operating with an unprepared burden (*A*), quoted above.

With a coke rate of 1960 lb (carbon 1666 lb), the carbon burnt at the tuyeres is about 1176 lb with an air blast of 86,500 ft³ at 600° C and a moisture content of 3·5 grains/ft³. The heat generated by the combustion of the carbon amounts to 4864 × 10^3 B.t.u. and this, with the sensible heat of the blast of 1723 × 10^3 B.t.u., gives a total heat supply of 6587 × 10^3 B.t.u.

Raising the blast temperature to 800° C provides an additional 598 × 10^3 B.t.u., giving a total heat supply of 7186 × 10^3 B.t.u. It is clear that, to maintain the same heat supply, the quantity of carbon consumed at the tuyeres can be reduced from 1176 to 1078 lb—a reduction of 98 lb, corresponding to roughly 6% of the total carbon consumed.

Similarly, if the blast temperature is raised by a further 200° C to 1000° C, the sensible heat of the blast (86,500 ft³) would be increased by a further 630 × 10^3 B.t.u., giving a total heat supply from the combustion of 1176 lb of carbon at the tuyeres of 7816 × 10^3 B.t.u. The amount of carbon to be consumed to ensure the same heat supply will be reduced in the inverse ratio to 991 lb—a reduction of 88 lb compared with the 800° C rate, or 185 lb compared with the 600° C blast temperature.

It will be noted that the reduction in carbon consumption at the tuyeres is less, numerically, for a temperature rise from 800° to 1000° C than for the rise from 600° to 800° C, but the fall in pounds reckoned as a percentage of the carbon consumed at the tuyeres is practically the same (8·3% and 8·1%) for the two steps. It follows that it is not practical to assess the reduction in coke rate in terms of pounds of carbon per 100° C rise in blast temperature.

A similar calculation of the effect of increase in blast temperatures with a fully prepared burden operating on a coke rate of 12·2 cwt with air blast of 56,000 ft³, water content of 11 grains/ft³ at 800° C, indicates that with an increase of blast temperature

Table V
HIGH BLAST HEAT AND STEAM ADDITIONS

	Normal Air Blast		Air and Steam
	10^3 B.t.u.		
Volume of blast, ft³	10,000		
Pre-heat, °C	800	1000	1000
Water vapour, grains/ft³	3·5	3·5	16
Water vapour, lb	5	5	22·85 lb*
Composition of blast, ft³			
Oxygen	2078	2078	2000
Nitrogen	7817	7817	7520
Water vapour	105	105	480
I. Tuyere Zone			
Carbon consumed, lb	135·1	135·1	142·1
Heat generated:			
by O_2 in blast	573·3	573·3	551·8
less C/H_2O	−14·4	−14·4	−65·9
	558·9	558·9	485·9
Sensible heat:			
Air	262·2	333·4	320·7
Water	3·4	4·3	20·8
	265·6	337·7	340·7
Total heat available at tuyeres	824·5	896·6	826·6
II. Tuyere Gas			
CO, ft³	4261 (35·0%)	4261	4480 (35·9%)
H_2, ft³	105 (0·9%)	105	480 (3·8%)
N_2, ft³	7817 (64·1%)	7817	7520 (60·3%)
	12,183	12,183	12,480
III. Stack Reaction [Assume 40% of CO and H_2 oxidized by Fe_2O_3]			
Heat evolved:			
Oxidation of CO	(126 lb) 550·8	550·8	(132·6 lb) 579·7
Oxidation of H_2	(0·22 lb) 11·6	11·6	(1·02 lb) 52·9
	562·4	562·4	632·6
IV. Total Heat Available:	1386·9	1459·0	1459·2
V. Heat Available:			
(*a*) per lb of tuyere carbon	10,270	10,810	10,270
(*b*) per 1000 ft³ blast	100	105·2	105·2
VI Rate of Carbon Combustion at Tuyeres	100	100	105·1

* 17·85 lb of steam per 10,000 ft³ blast is equivalent to 100 lb of steam per ton of iron at 56,000 ft³ blast

from 800° to 1000° C the carbon consumed at the tuyeres would fall from 800 lb by 68 lb—8·5%. This is to be compared with the 87 lb carbon reduction for the same blast-temperature rise with the unprepared burden. While the decrease in carbon consumption at the tuyeres is less for the prepared burden measured in pounds, the percentage reduction in the coke rate is practically the same as for the same temperature rise, namely, 5·86% compared with 5·88% for the same temperature range.

It follows that if external heat is supplied via the blast or other means, the rate of carbon consumption at the tuyeres per ton of iron made will fall and the iron production rate will increase. While the numerical value of the improvement will vary, an increase of 200° C in the blast temperature should lead to a decrease of about 6% in the coke rate at the lower temperature.

This first approximation deals only with thermal conditions at the tuyeres; certain secondary factors require consideration. The reduction in the coke rate naturally leads to a reduction in the volume of gas generated in the tuyere zone per ton of iron made. With traditional practice and the relatively little use of the reducing power of the gas in the stack, this reduction of volume and velocity may lead to even greater economy, but in the highly efficient modern practice little further benefit can be looked for from this factor of volume reduction.

While there can be little doubt as to the benefit of increased blast temperature from the thermal aspect, certain practical factors demand consideration. With temperatures of 900° C or higher, certain difficulties arise in the provision of satisfactory refractories in the stoves and there will be a tendency towards a fall in the thermal efficiency of the stoves. This can be counterbalanced by modification of design and probably by the incorporation of metal heat-exchangers on the exit side of the stoves.

Certain modifications will also be required in the design and construction of the tuyeres to give satisfactory life and prevent undue radiation losses at the higher temperatures. Experimental types of tuyeres as regards material, insulation, or cooling are already in use, but the experience gained so far is not adequate to formulate definite recommendations.

A most important practical factor is the effect of the higher blast temperature on the operating conditions in the furnace hearth and bosh. It was demonstrated several years ago by Korevaar[6] that with higher blast temperatures and a higher temperature generated at the tuyeres, there is a tendency to diminish the combustion zone and for the melting zone of the descending stock to approach the tuyere zone until the condition is reached where unmelted material actually enters the combustion zone. These conditions lead to a slowing down of the rate of combustion, a loss of production, and deterioration of iron quality, together with a tendency to 'stickiness' in the furnace driving. As a result, it has been found necessary to counteract the higher flame intensity and tuyere gas temperature by the introduction of a cooling agent in the form of steam.

Use of Steam in Air Blast

Many years ago the attention of blast-furnace operators was drawn to the effect of the varying amounts of water vapour in the air of the blast. It was accepted that the presence of the water vapour was deleterious to efficiency and, in some cases, considerable sums were expended for the installation of equipment to dry the blast air before it entered the furnace. This practice has not been maintained for economic reasons. To-day, however, there is a definite tendency towards increasing the moisture content by the addition of steam under regulated conditions. It is therefore desirable to examine the principles involved.

It is well known that the quantity of water vapour in the atmospheric air varies from time to time, and particularly in countries with continental climates. These variations in moisture content naturally lead to variations in furnace operation and it is generally accepted that control of the water

vapour content is beneficial, if only from the point of view of ensuring regular operation of the furnace.

There is also a trend towards the regulation of the water vapour as a positive control of furnace operation.

As stated above, an increase in the blast temperature leads directly to a decrease in the coke rate, but above certain practical limits it tends towards a lower rate of combustion and more difficult driving of the furnace. The addition of water vapour (steam) to the air blast at these higher temperatures tends to lower the flame temperature to its previous level and to restore the smooth fast-working condition of the hearth.

Since the reaction of steam with carbon at the high temperature of the tuyere zone is endothermic and further heat is lost by the reduction of air per 1000 ft³ of blast, the introduction of steam into the air blast must produce a lowering of the flame temperature in the tuyere zone. This is counterbalanced to some extent by the sensible heat of the steam, but there is a net heat loss in the flame area of about 4100 B.t.u. for each lb of steam in the blast (*see* Appendix *B*).

It was indicated earlier that the blast requirement for an efficient furnace with air blast at 800° C is about 56,000 ft³. If the blast temperature is raised to 1000° C, the additional sensible heat will be of the order of 420,000 B.t.u. per ton of iron. In modern practice this increase of heat supply is counterbalanced by enough steam to restore, more or less, the thermal conditions for smooth working. The amount of steam to be added for the rise of 200° C in blast temperature can be estimated at about 100 lb per ton of iron, or 12·5 grains/ft³, giving a total water vapour of about 16 grains/ft³ of blast blown. This estimate may be compared with current practice in Russia, Sweden, and other countries.*

Since it would appear on the surface to be an anomaly to increase the heat supply and at the same time apply a cooling agent, an analysis is given in Table V of the conditions prevailing with ordinary blast at 800° and 1000° C and blast with a moisture content of 16 grains/ft³ at 1000° C.

It will be seen from this table that, for each 10,000 ft³ of blast, raising the temperature from 800° to 1000° C raises the heat available at the tuyeres by about 72,000 B.t.u. If sufficient steam is added to the blast to raise the moisture content to 16 grains/ft³, the cooling effect of the water reduces the available heat at the tuyeres to practically the same level as at 800° C blast temperature. The increase in hearth temperature is entirely neutralized by the effect of the water vapour.

It is now necessary to examine the effect of this water vapour in the stack. The first effect of the additional water is to give a small increase in gas volume (2·4%) but, much more important, to raise the CO and H_2 content from 35·9% to 39·7%. In the table, it is assumed that these ascending gases are oxidized to the same degree (40%) in the stack by the reduction of iron oxide. On this basis the amount of heat generated in the stack at temperatures between 450° and 800° C shows an increase of about 70,000 B.t.u., which is exactly equivalent to the cooling effect of the water reacting in the tuyere zone. The total amount of heat made available in the furnace system is precisely the same. The temperature conditions in the bosh and tuyere zone necessary to ensure smooth working of the stock are re-established, and in effect the whole of the heat provided by the increased sensible heat of the gas is transferred to the stack column with equally beneficial effects to the furnace operation. It is to be noted that the heat available per pound of carbon burnt at the tuyeres with a preheat of 1000° C, plus moisture

Table VI

OXYGEN-ENRICHED BLAST

(Oxygen—24·5%: Blast Heat—800° C)

	Normal Air	Enriched Air	Enriched Air plus Steam
	10³ B.t.u.		
Volume of blast, ft³	10,000	10,000	10,000
Water vapour, grains/ft³	3·5	3·5	19·5
Water vapour, lb	5	5	27·85
Composition of blast, ft³			
Oxygen	2078	2424	2307
Nitrogen	7817	7471	7108
Water vapour	105	105	585
I. Tuyere Zone			
Carbon consumed, lb			
Oxygen in air	131·8	153·7	146·3
Water vapour	3·3	3·3	18·6
	135·1	157·0	164·9
Heat generated:			
C with air	573·3	668·6	636·4
C with H_2O	−14·4	−14·4	−80·3
	558·9	654·2	556·1
Sensible heat at 800 °C			
Air	262·2	262·2	249·5
Steam	3·4	3·4	19·1
	265·6	265·6	268·6
Total heat at tuyeres	824·5	919·8	824·7
II. Tuyere Gas			
CO, ft³	4261 (35·0%)	4953 (39·5%)	5199 (40·3%)
H_2, ft³	105 (0·9%)	105 (0·9%)	585 (4·5%)
N_2, ft³	7817 (64·1%)	7471 (59·5%)	7108 (55·2%)
	12,183	12,529	12,892
III. Stack Reaction [Assume 40% of CO and H_2 oxidized by Fe_2O_3]			
Heat evolved by:			
$CO \rightarrow CO_2$	550·8	640·6	672·8
$H_2 \rightarrow H_2O$	11·6	11·6	64·4
Total in stack	562·4	652·2	737·2
IV. Total Heat Available from Tuyere Carbon	1386·9	1572·0	1561·9
V. Relative Rates of Tuyere Carbon Consumption	100	116·2	122·0
VI. Heat Available:			
(*a*) per lb tuyere carbon	10,266	10,010	9472
(*b*) per 1000 ft³ blast	100	113·3	112·6

* Strassburger (National Steel Corporation, U.S.A.) gives 1 grain/ft³ for 30° F rise of blast temperature.

addition, is the same as for normal blast with a preheat of 800° C, but the rate of operation of the furnace with constant blast volume is raised by 5%.

OXYGEN ENRICHMENT OF BLAST

The proposal to enrich the air blast by the addition of oxygen is certainly not new. Experimental trials were made more than twenty years ago on a small furnace at Oberhausen. Practical difficulties were encountered in blowing due to sticking in the bosh because of the high local temperatures, and with the low volume of blast the sensible heat in the ascending gases was insufficient to carry away the moisture of the burden which was deposited in the upper parts of the stack. Further, the prevailing price of oxygen made the proposition unattractive from the economic aspect.

The problem was further examined by the author and his colleagues in Berlin in 1938. It was decided that the practical difficulties could be overcome and that further trials should be made as soon as oxygen could be made available at a satisfactory price.

The advent of tonnage oxygen in the post-war period has brought this application into the realm of practical operations. It is self-evident that with blast of a given volume, but enriched with oxygen, the weight of carbon burnt at the tuyeres per cubic foot of blast will increase and therefore the rate of carbon throughout per cubic foot of blast. Consequently, iron production will increase.

Equally, while the heat generated by the combustion of each pound of carbon will not increase, the volume of tuyere gas produced per pound of carbon will decrease and the temperature in the tuyere zone will show a substantial rise. This, in turn, will develop a tendency to sticking in the bosh and a slowing-down of blowing and of production. As with high blast heat, the remedy is to be found in cooling the tuyere zone by the addition of steam to the blast air. As would be anticipated, the amount of steam required for this purpose is related to the degree of enrichment of the blast.

To illustrate the effect of oxygen enrichment and this relationship between oxygen content and steam addition, a preliminary analysis of the conditions at the tuyeres and in the stack is given in Table VI. For this analysis a comparison is made of the thermal conditions when blowing 10,000 ft³ of (*a*) normal atmospheric air with 3·5 grains of moisture per cubic foot and preheated to 800° C; (*b*) air enriched to 24·5% O_2 content; and (*c*) enriched air with additions of steam to give 19·5 grains of moisture per cubic foot.

The table shows that with enriched air the weight of carbon burnt per 1000 ft³ of blast will rise from 13·5 to 15·7 lb—an increase of 16%—and the rate of production will rise. At the same time, the heat available at the tuyeres per 1000 ft³ of blast will rise from 82,500 to 92,000 B.t.u.—an increase of 11·5%—and since there is a relatively small increase in the tuyere gas volume (2·8%) there will be a marked increase in temperature and a pronounced resistance to blowing.

The addition of steam to the enriched blast to raise the moisture content to 19·5 grains/ft³ results in the cooling of the tuyere zone to the level of the ordinary atmospheric blast and thereby restores smooth operating conditions. While the thermal levels are restored, it is important to note that the weight of carbon burnt at the tuyeres rises from 13·5 lb with ordinary air to 16·5 lb per 1000 ft³ of enriched moist blast—an increase of 22%. On the other hand, the quantity of heat available at the tuyeres per pound of carbon consumed falls from 6100 B.t.u. with normal air to 5000 B.t.u.

As in the case of higher blast temperatures, it is necessary to examine the conditions in the stack resulting from the change in blast quality. The volume of gas generated at the tuyeres shows an increase of about 6% but, much more important, the CO and H_2 content rises from 35·9% to 44·8%. If it is assumed that this enriched gas is utilized for ore reduction only to the same degree as ordinary blast (40%), the heat generated in the stack shows an increase of 17,500 B.t.u. per 1000 ft³ of blast and the overall heat available per 1000 ft³ of blast shows an increase of 12·6%.

The effect of the enrichment to 24·5% O_2, together with a moisture content of 19·5 grains, is therefore to increase the rate of carbon consumption at the tuyeres by 22% and to increase the heat available from the tuyere carbon by about 12·5%, but the overall heat available per pound of carbon burnt at the tuyeres falls from 10,266 to 9472 B.t.u.—a fall of 7·8%. Theoretically, this would correspond to an increase of 7·8% in the carbon consumed at the tuyeres per ton of iron produced. It is important to note that in the modern practice *B* in Table I, the carbon consumed at the tuyeres is about 70% of the total carbon consumed for heat generation and the theoretical increase in carbon consumption per ton of iron would be therefore about 5%.

SELF-FLUXING SINTER

Among the significant factors in modern technique, the development of self-fluxing sinter is of special importance, and especially in lean-ore practice. In the modern practice, the limestone and magnesian carbonates, which are required to flux the gangue of the ore and the coke ash, are incorporated in the sinter mix and charged into the furnace as sinter. The advantages of this procedure are obvious.

In the comparison given in Table I, the heat required in the unprepared burden for the decomposition of the carbonates is estimated at about 5·5% of the total heat requirement. If this decomposition is carried out in the sintering operation there is a corresponding direct reduction in the heat consumed in the blast-furnace. Equally important is the heat absorbed and coke consumed in the reduction of the CO_2 formed in the furnace from the carbonates. In Table I this accounts for a further 3% in the heat requirement and a direct consumption of 66 lb of carbon for this operation. The addition of the fluxes in the sinter mix therefore gives a direct reduction in the heat requirement of the blast-furnace of some 1 million B.t.u., or 8% of the total.

A secondary effect is also of importance. It is well known that when ore is sintered there is a tendency for the iron oxide and silica of the ore to

combine to form the mineral fayalite, which can only be reduced in the high-temperature zones of the furnace. If lime is added to the sinter mix this tendency is inhibited by combination of the SiO_2 with CaO and the iron oxide of the ore remains as oxide capable of reduction by CO gas, thereby promoting greater efficiency in the furnace. It will also be accepted that the addition of lime and magnesia to the sinter mix instead of being separate constituents of the burden will tend towards a more uniform analysis of the burden, which also promotes efficiency and regularity of operation.

While these factors are definitely significant with furnaces operating on rich-ore burdens with a slag weight of 1000–1200 lb, they become far more important with lean-ore practice, in which the slag weight may rise to 2800–3000 lb. The economies possible with lean-ore are of the order of 2·5 million B.t.u. or 15% of the total heat requirement. The advantages of using 100% sinter of self-fluxing quality have been fully demonstrated by the development work of Elliot and his colleagues at Appleby-Frodingham, and for rich ore at Domnarvet and in the U.S.S.R.

SLAG COMPOSITION

In a paper to the Institute in 1936, the author directed attention to the importance of the blast-furnace slag composition, its viscosity, and the speed of operation of the furnace. Experimental work carried out by Professor Engell for the author in Berlin in 1938 gave valuable information on some of the factors governing these differences in viscosity. This work has been confirmed by the recent research of Baldwin[7] on the properties of blast-furnace slag, where it was shown that the viscosity/temperature curves are of two distinct types: (*a*) those in which the viscosity decreases gradually with change of temperature, and (*b*) those in which the viscosity changes suddenly and within a narrow temperature range.

It may be suggested that this difference in type of slag is one of the factors responsible for stickiness in the bosh zone which is often experienced in certain practice.

If the slag formed has a large temperature difference between the solidus and the liquidus, it means that the slag formation is spread over a relatively long time and greater distance in the bosh of the furnace. During this transition period the slag formed is changing in composition, usually absorbing further basic oxides, and is never fully fluid. These conditions definitely promote stickiness and this is further accentuated by variations in temperature in different parts of the bosh. The slag which has been formed in one part may, on entering a cooler zone, become solid or definitely of higher viscosity.

On the other hand, if the furnace is burdened to give a slag of eutectic composition, the temperature range of slag formation is reduced to a minimum and the slag melts rapidly and at a definite level in the furnace. This tends to give a clean separation of the slag constituents from the coke and liquid metal, thereby promoting smoothness of operation.

The use of self-fluxing sinter makes a definite contribution to this factor, since the acid and basic constituents of the slag are already in close association in the desired proportion, thereby promoting a sharp, definite, slag-melting range.

SUMMARY

The basis of practically all the modern developments in blast-furnace operation lies in the preparation of the ore before charging into the furnace. The object of the ore preparation is to secure uniformity of composition of the burden by thorough mixing of the various constituents and, as nearly as possible, uniformity of size of pieces of material. In any case, all small pieces below 10 mm should be removed and sintered. The optimum results are attained by sintering 100% of the burden.

This pre-preparation of the burden promotes greater permeability and easier blowing of the stock. Therefore, a higher rate of blowing can be maintained and, with uniformity of sizes, a greater efficiency can be attained in the use of the furnace volume.

The overall heat requirement is also reduced by sintering the whole of the burden, including the fluxes, and this gives a direct reduction of the coke rate. The combination of complete preparation with self-fluxing sinter gives a higher rate of blowing and a lower coke rate, both factors contributing to higher production.

The coke rate can also be reduced by using higher temperatures for the hot blast. This reduces the coke rate directly and increases the rate of heat supply per 1000 ft^3 of blast. Enrichment of the blast by oxygen also raises the speed of operation by increasing the weight of carbon burnt at the tuyeres per cubic foot of blast. Both these factors have definite operating limits because the higher temperatures generated at the tuyeres tend to stickiness in the tuyere zone and bosh. This tendency can be counteracted in both cases by the addition of steam to the air blast. The reaction of the steam with coke lowers the temperature of the combustion zone but generates CO and H_2, enriching the tuyere gas. This gas ascending the stack reduces the iron oxide at temperatures between 450° and 800° C, thereby generating heat in the cooler parts of the furnace and reducing the amount of carbon used for the reduction of the iron oxide. This generation of heat in the stack can more than counterbalance the reduction of heat at the tuyeres caused by the addition of steam.

The overall thermal efficiency of the furnace depends upon the extent to which the ascending gases are utilized for the reduction of ore. In the examples quoted, it is assumed that this degree of utilization of the gas is at the same value (40%), irrespective of the CO and H_2 content. It is self-evident that the degree of use of the gases must depend upon the relative gas/solids contact and upon the richness of the gas in the CO and H_2, and particularly the hydrogen.

Unfortunately, little or no research work has been undertaken on the distribution of the gases in the stock column and it is specially urged that work on this aspect of furnace operation should be carried

out urgently in view of the importance of this factor. Attention may be drawn to the work which is being carried out on this problem in the U.S.S.R. by means of radioactive isotopes.

Since the reactions which occur in the stack are critical as regards the performance of the furnace, it is recommended that a standard of sinter quality should be established. This standard should be the measure of the reducibility of the sinter when heated in a stream of CO or H_2 for a period of 2 h at a temperature of, say, 750° C.

Attention is also drawn to the importance of studying slag composition as a factor in minimizing stickiness of operation in the bosh zone.

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APPENDIX A

Comparison of Practice

	Practice A: Unprepared Burden	Practice B: Prepared Burden
Ore	58% Fe	58% Fe
Sinter	Nil	100% self-fluxing
$CaCO_3$	805 lb	135 lb (for coke ash)
$MgCO_3$	92 lb	Nil
Slag made	1100 lb	1000 lb
Water in:		
burden and coke	185 lb	75 lb
blast	43·25 lb	88 lb
Coke rate	17·5 cwt (1960 lb)	12·2 cwt (1366 lb)
Carbon	1666 lb	1161 lb
Air blown	86,500 ft³	56,000 ft³
-temperature	600° C	800° C
-moisture	3·5 grains/ft³	11·0 grains/ft³
Blast-furnace gas	122,000 ft³	79,500 ft³
Composition-N_2	56·0%	55·6%
-CO	32·8%	25·8%
-CO_2	10·7%	17·2%
-H_2	0·5%	1·4%
Ratio CO/CO_2	3/1	1·5/1
Calorific value	105 B.t.u./ft³	87 B.t.u./ft³

APPENDIX B

Cooling Effect of Steam at Tuyeres

The cooling effect at the tuyeres produced by the introduction of steam into the blast is two-fold in character—the direct cooling due to the decomposition of the steam and the loss of heat generation caused by replacement of air.

I. Decomposition of Steam

The steam reacts with the carbon of the coke according to the equation:

$C + H_2O \rightarrow CO + H_2$ — 51,930 B.t.u.

Each lb of steam consumed absorbs 2884 B.t.u.

II.—Replacement of Air

Each lb of steam in the blast replaces 21 ft³ of air.

Weight of O_2 in 21 ft³ air	= 0·373 lb
Carbon burnt by 21 ft³ air	= 0·28 lb
Heat generated at tuyeres by 0·28 lb carbon	= 1217 B.t.u.
Total heat loss by introduction of steam	= 4101 B.t.u./lb

With oxygen-enriched blast (24·5% O_2):

21 ft³ blast contains	0·435 lb O_2
Carbon burnt by 21 ft³	0·326 lb
Heat lost	1420 B.t.u.
Total heat loss of steam	4304 B.t.u./lb

III. Carbon Consumption

Each lb of H_2O consumed	0·667 lb C
Addition of 1 lb steam *increases* carbon consumption:	
(i) with normal air	0·387 lb
(ii) with enriched blast (24·5% O_2)	0·34 lb

APPENDIX C

Zone Reactions—Unprepared Burden (Practice A)

MATERIALS USED AND GAS GENERATED

	Carbon Consumed, lb	Oxygen Consumed, lb	Gas Generated, ft³ CO	CO_2	H_2	N_2	Total
Zone 4—1000–1500° C							
(*a*) Air blast—86,500 ft³	1147·2	1529·6	36,173	...	...	68,335	
(*b*) Water—43·25 lb (910 ft³)	28·8	38·4	910	...	910	...	
(*c*) Carbon in metal	94·2	...	...	...	...	...	
Tuyere Zone	1,270·2	1568·0	37,083	...	910	68,335	106,328
(*d*) Reduction SiO_2, etc.	34·3	45·7	1080	...	...	...	
Zone 3—800–1000° C							
(*a*) Reduction of carbonate CO_2 to 3 CO : 1 CO_2	65·8	...	4152	1384	...	...	
(*b*) Reduction of iron oxide to CO	295·7	394·3	9325	...	...	...	
Zone 2—450–800° C							
(*a*) Oxidation of 1·2 lb H_2	...	9·6	...	...	−227	...	
(*b*) Reduction of Fe_2O_3 by CO	...	492·2	−11,640	11,640	...	...	
	1666·0	2509·8	40,000	13,024	683	68,335	122,042

APPENDIX D

Zone Reactions—Unprepared Burden (Practice A)

HEAT GENERATION AND USE (10^3 B.t.u.)

	Heat Supply		Heat Use	Sensible Heat in Gas
Zone 4—1000–1500° C				
Sensible heat of blast	1723·3	To Heat burden	687·0	
Combustion of carbon—		Decompose water	251·3	
at tuyeres—1176 lb	5115·6	Reduce SiO_2 etc.	513·0	
in bosh—34·3 lb	149·2	Radiation losses, 90%	508·2	
Total—Zone 4	6988·1		1959·5	5028·6
Zone 3—800–1000 °C				
C → CO (295·7 lb)	1286·3	To Heat burden	260·0	
		Decompose carbonate, Reduce CO_2 to CO	1054·7	
		Reduce Fe_2O_3 to metal, 44% of total	2925·8	
		Radiation losses, 10%	56·0	
Total—Zone 3	1286·3		4306·5	2008·4
Zone 2—450–800 °C				
Oxidation of H_2 → H_2O	62·5	To Heat burden	455·0	
Oxidation of CO → CO_2	3765·5	Reduce Fe_2O_3 (56%)	3736·5	
Total—Zone 2	3828·0		4191·5	1644·9
Zone 1—Below 450 °C				
	Nil	To Heat burden	565·0	
		Evaporate water	213·0	
			778·0	
		Sensible heat of B.F. gas at 220° C	866·9	
Total—Zone 1	Nil		1644·9	866·9
	12,102·4		12,102·4	

APPENDIX E

Zone Reactions—Prepared Burden (Practice B)

MATERIALS USED AND GAS GENERATED

	Carbon Consumed, lb	Oxygen Consumed, lb	Gas Generated, ft³ CO	CO_2	H_2	N_2	Total
Zone 4—1000–1500 °C							
(*a*) Air blast—56,000 ft³	741·8	989·1	23,390	...	...	44,240	
(*b*) H_2O/C—88 lb	58·7	78·2	1850	...	1850	...	
(*c*) C in metal	94·2	...	...	...	...	...	
Tuyere Zone	894·7	1067·3	25,240	...	1850	44,240	71,330
(*d*) Reduction of SiO_2, etc.	34·3	45·7	1080	...	...	...	
Zone 3—800–1000 °C							
(*a*) Reduction of carbonates 1·5 CO : 1 CO_2	7·0	...	440	290	...	...	
(*b*) Reduction Fe_2O_3 to CO	225·0	300·0	7095	...	...	...	
Gas at 800° C			33,855	290	1850	44,240	80,235
Zone 2—450–800 °C							
(*a*) Oxidation of H_2 (40%)	...	31·3	...	...	−740	...	
(*b*) Oxidation of CO (40%)	...	564·8	−13,344	13,344	...	...	
Totals and Gas at 450° C	1161·0	2009·1	20,511	13,634	1110	44,240	79,495

APPENDIX F

Zone Reactions—Prepared Burden (Practice B)

HEAT GENERATION AND USE (10^3 B.t.u.)

	Heat Supply		Heat Use	Sensible Heat of B.F. Gas
Zone 4—1000–1500 °C				
Sensible heat of blast	1545·0	To Heat burden	632·0	
Combustion of carbon		Decompose water	511·0	
at tuyeres—800·5 lb	3482·2	Reduce SiO_2, etc.	513·0	
in bosh—34·3 lb	149·2	Radiation losses, 90%	430·0	
Total—Zone 4	5176·4		2086·0	3090·4
Zone 3—800–1000 °C				
C → CO—225 lb	978·8	To Heat burden	255·0	
		Decompose carbonates }	145·0	
		Reduce CO_2 }		
		Reduce Fe_2O_3 (37%)	2472·4	
		Radiation losses, 10%	48·0	
Total—Zone 3	978·8		2920·4	1148·8
Zone 2—450–800 °C				
CO → CO_2 (998·4 lb)	4321·0	To Heat burden	440·0	
Oxidation of H_2 (3·91 lb)	203·5	Reduce Fe_2O_3 (63%)	4200·0	
Total—Zone 2	4524·5		4640·0	1033·3
Zone 1—Below 450 °C				
	Nil	To Heat burden	565·0	
		Evaporate water	86·0	
			651·0	
		Sensible heat of blast-furnace gas	382·3	
Total—Zone 1	Nil		1033·3	382·3
	10,679·7		10,679·7	

The Adiabatic Vacuum Calorimeter from 600° to 1600° C

SPECIFIC HEATS OF TITANIUM, 44% Cr–Fe ALLOY, AND A LOW-ALLOY STEEL

By I. Backhurst, M.Sc.

Introduction

FOLLOWING ON WORK done at the National Physical Laboratory with an adiabatic vacuum calorimeter by Awbery and Griffiths,[1] Awbery and Snow,[2] and Awbery and Challoner[3] on iron and steel up to 950° C, it was decided to try to extend the working temperature range to reach the molten state of iron.

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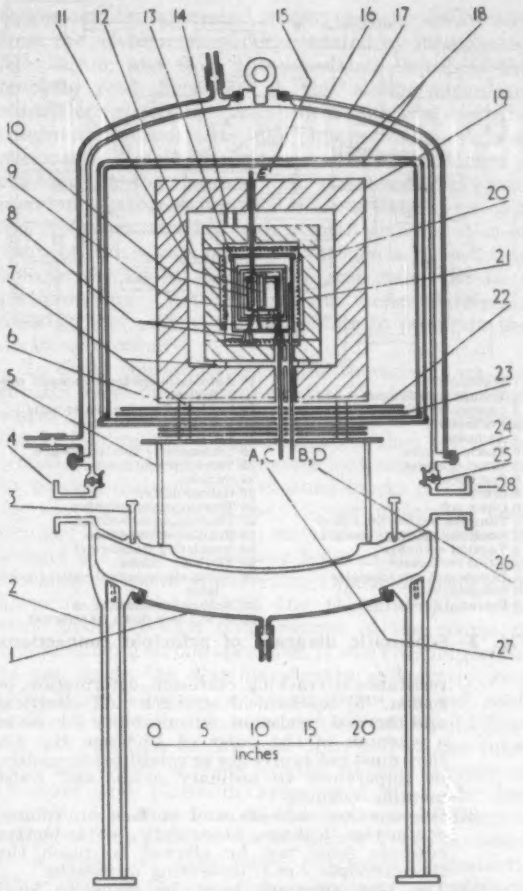
SYNOPSIS

The upper temperature limit of the adiabatic vacuum calorimeter has been extended from 950° to 1600° C. The instrument described is mainly automatically controlled and gives a continuous record of thermal capacity over its temperature range beginning at about 600° C. It is adapted for either solid or liquid metal specimens and has been applied to the measurement of the thermal capacities of titanium from 590° to 1080° C, a 44% chromium–iron alloy from 500° to 1100° C, and an alloy steel, containing 1·09 chromium, 0·69 manganese, 0·315 carbon, and 0·20 silicon per cent. by weight from 540° to 1600° C. The $\alpha \rightarrow \beta$ titanium transition heat was 77 J/g or 880 cal/g-atom and that of the chromium–iron $\sigma \rightarrow \alpha$ transition 27½ J/g or 356 cal/mole. A latent heat of fusion of 249 J/g was found for the steel. 1489

For materials such as iron or steel showing phase changes in the high-temperature region studied, the adiabatic method, which involves only a relatively small change in temperature in the process of measurement, has a substantial advantage in principle over the 'drop' method, in which the specimen is quickly brought to near room temperature, where its crystalline and granular state may be much different and largely conditioned by its rate of cooling. If with rising temperature a transition occurs that is slow to reverse with falling temperature, the drop method may be practically inapplicable. On the other hand, experimental difficulties with the adiabatic method increase greatly as the temperature range is extended upwards so that, although the drop method yields thermal capacity only indirectly, it is the method which has been mostly used and, as far as the author is aware, the adiabatic method has not before been used above 950° C.

In both methods it is the differential coefficient of enthalpy with respect to temperature that is needed, and in practice an approximation must be made by dividing a difference in enthalpy by the corresponding difference in temperature so that a mean value of the thermal capacity over a particular temperature interval is found. At a given temperature region the experimental error in both enthalpy and temperature will be relatively independent of the size of the temperature interval, so that the percentage error in both the enthalpy difference and temperature difference and so in the thermal capacity will increase substantially as the temperature interval is reduced. If the thermal capacity changes only slowly over a temperature region, both methods are favoured since the temperature interval may be taken large, and the drop method may be expected to give a good result. In the region of a phase transition where the thermal capacity may be changing rapidly, the temperature interval must be made small. Here the drop method is the one more adversely affected and if applicable at all it will, unless the transition heat is large, usually give only a low-accuracy measure of it and be unable to follow the variation in thermal capacity. In the adiabatic method, however, since the enthalpy difference is measured more directly, being the product of a heating rate and time, there may be sufficient accuracy to follow the variation of thermal capacity fairly closely. In the drop method, the enthalpy difference sought appears as the difference between two relatively much larger measured values, and the percentage error of measurement is much magnified in the deduced thermal capacity.

A great advantage of the adiabatic method is that it may be made continuously recording to cover a wide range of temperature in one experiment, and no thermal values of special interest can be accidentally missed. On the other hand, if the thermal capacity values obtained are integrated with respect to temperature to obtain an enthalpy difference corresponding to an appreciable temperature range, the errors will be largely cumulative and the enthalpies deduced may be more in error than those measured directly by the drop method. However, some of the errors balance themselves out, and in any case the percentage error on the total enthalpy difference cannot be greater than the maximum percentage error on the thermal capacity values being integrated. It follows that the adiabatic and drop methods are largely complementary and that to gain the best knowledge of the thermal constants both methods should be available.



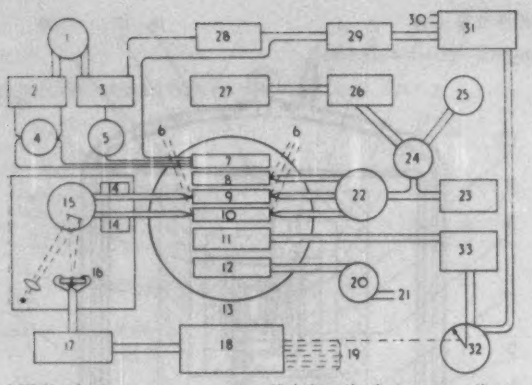
1 Water-jacket
2 Tubular steel legs
3 Steel framework for clamping current leads against water-cooled base
4 Connecting-flange to pump line
5 Four-legged steel table
6 Steel square plate
7 Thermal insulating supports
8 Alumina cone supports
9 Metal under test
10 Alumina crucible
11 Rhodium–platinum heater inside alumina tube
12 Rhodium–platinum radiation shields
13 Molybdenum enclosure
14 Thermal insulating supports
15 Thermocouple *E* in alumina sheath in metal under test
16 Steel water-jacket
17 Steel bell
18 Cylindrical nickel radiation shields
19 Rectangular enclosure of low-thermal-conductivity bricks
20 Rectangular enclosure of ceramic blocks
21 Main heater grid of tungsten wire
22, 23 Nickel radiation shields
24 Watertight gasket
25 Rubber gasket vacuum joint
26 Two thermocouples *B* and *D* in alumina sheath on molybdenum enclosure
27 Two thermocouples *A* and *C* in alumina sheath on crucible
28 Connecting flange to pump line

Fig. 1—Adiabatic vacuum calorimeter for temperatures from 600° to 1600° C

General Considerations for Calorimeter Design

In extending the temperature range of the adiabatic calorimeter, the guiding considerations were:

(i) Materials used need to withstand high temperatures for long periods while retaining as far as possible most of the following properties: (*a*)



1 Wattmeter
2 Voltage transformer
3 Current transformer
4 Voltmeter
5 Ammeter
6 Thermocouples
7 Internal heater
8 Specimen
9 Crucible
10 Outer pot
11 Tungsten heaters for 1 face
12 Auxiliary platinum heaters
13 Vacuum enclosure
14 500-Ω resistances
15 Double-coil galvanometer
16 Selenium cells
17 Potential divider
18 Automatic electro-pneumatic controller
19 Leads to 5 similar heater units
20 Regulating transformer
21 a.c. mains
22 Continuously rotating switch
23 Vernier potentiometer
24 Switch
25 Galvanometer
26 Thermocouple amplifier
27 Thermocouple recorder
28 Regulating resistance
29 Regulating transformer
30 230-V a.c. mains
31 Automatic constant-voltage regulator
32 Regulating transformer
33 10 to 1 step-down transformer

Fig. 2—Schematic diagram of principal connections

resistance to cracking, corrosion, deformation, or fusion, (*b*) mechanical strength and electrical and thermal insulation, (*c*) suitability for use in a vacuum of the order of 10^{-4} mm Hg, i.e. they must not evolve gas or volatilize too readily, be impervious to ordinary gases, and resist metallic vapours

(ii) Gaseous ion currents and surface or volume conduction leakage, electrolytic, or inductive currents must not be allowed to reach the thermocouple e.m.f. measuring apparatus

(iii) The best approach must be made to ideal conditions for adiabatic operation, i.e. both inner and outer enclosures should be as uniform in temperature as possible and the excess temperature of the more variable outer enclosure over the inner should be minimized and evenly alternating positive and negative with time. Transfer of heat between the two enclosures for a given difference of temperature between them must be minimized

(iv) Metal specimens to be studied in the molten as well as the solid state

(v) Accessibility must be good to facilitate assembly.

Restrictions imposed by basic limitations of the properties of materials are, of course, the most serious of any in high-temperature work. To meet the requirements of (iii), a good vacuum was needed to eliminate gaseous thermal convection and reduce thermal conduction. Preliminary work showed that the provision of radiation screens between the two enclosures was also essential. A mainly automatic control was also necessary to maintain the temperature balance between the enclosures. To meet (ii) the thermocouples were enclosed in alumina sheaths wound with platinum ribbon electrically earthed. To avoid trouble from electrolytic e.m.f.'s, which become appreciable with alumina above about 1350° C, the thermocouple circuits were kept separate and the balancing couples could not be connected in opposition. The use of a crucible to meet (iv) imposed a condition for reasonable accuracy of measurement in that its thermal capacity should not be too large compared with that of the specimen. If alumina, the crucible had to be large enough to contain a weight of about 4 lb so that its thermal capacity should not be more than one-third to one-half of that of its content if this were steel.

Description of Calorimeter

The calorimeter is shown diagrammatically in Figs. 1 and 2. The crucibles used were cylindrical, $2\frac{3}{4}$ in. dia. and $3\frac{3}{4}$ in. high, and were of alumina when the specimen was to be melted. Molybdenum crucibles, which could be made with much lower thermal capacity, were used as inner enclosures for some of the solid-state experiments. The specimen was heated by an internal heater made by springing a rhodium–platinum spiral inside a thin-walled, $\frac{1}{4}$-in. dia. tube of recrystallized alumina, coating the wire with alumina slip, and baking. The crucible was enclosed by three concentric radiation screens, each 0·004 in. thick. At first these were of rhodium–platinum alloy, but molybdenum was found to be quite effective and more convenient because of its greater rigidity.

This brought the minimum convenient size of the cylindrical pot with lid forming the outer enclosure of the adiabatic system to 6 in. dia. and $7\frac{1}{2}$ in. high. Alumina pots were used at first, but if sufficiently thin they are difficult to make of good shape and it was found possible to use pots of $\frac{1}{2}$-mm thick molybdenum, which had the advantage of introducing much less thermal lag and so improved the sensitivity.

The pot was heated by radiation from 48 spirals of 24 s.w.g. tungsten wire held in equal groups in the recessed portions of six ceramic blocks forming a rectangular enclosure. Leads to the tungsten spirals were of 18 s.w.g. molybdenum wire. Connection was made by pushing a molybdenum wire through three turns of the close-fitting tungsten spiral and then out through the side of the spiral to project $\frac{1}{2}$ in., bending this projecting end back, and hammering it hot to clip and partially embed the three turns of the tungsten spiral in the fold of the molybdenum wire. The connection when newly made had a measurable resistance compared with that of the spiral but, after use in the vacuum enclosure for a short time, it formed a clean bright joint of negligible resistance and was mechanically strong.

Each of the six heater units had the molybdenum leads to it connected in parallel outside the supporting ceramic block and fed by a separate transformer. Potential leads were attached and brought to terminals outside the vacuum enclosure, so that the power used in each of the heater units could be measured. Ammeters in the primary circuits of the six variable-tapping autotransformers used to supply the heater transformers gave readings nearly proportional to the power taken. The settings of these autotransformers, although normally made by the pneumatic servomotor of an automatic controller, could be adjusted by hand when necessary to maintain equality of the power dissipated in each of the heater units.

Separated by a gap of about $1\frac{1}{2}$ in. from the ceramic block enclosure was a surrounding enclosure built of 9 in. × $4\frac{1}{2}$ in. × 3 in. low-thermal-conductivity bricks.

Distributed as evenly as possible in the 1½-in. gap were 30 rhodium–platinum-wound alumina tubes which were used as preliminary heaters up to about 500° C for drying-out purposes.

Two nickel radiation screens surrounded the brick enclosure and below these were several additional screens of nickel, separated by pieces of low-thermal-conductivity brick, the whole standing on a steel table inside a 3-ft dia. steel vacuum enclosure equipped with water jackets. Two independent pumping units were used, each consisting of a silicone–oil diffusion pump backed by a rotary oil pump. About 0·06μ was obtained at room temperature and up to 0·7μ at 1600° C, the pressure being measured by an ionization gauge placed inside the lower part of the steel enclosure. All vacuum connections were metal.

Temperature equality between the crucible and the surrounding pot was sought by comparing the readings of rhodium–platinum thermocouples contained in alumina sheaths, one alumina tube being attached to the inside of the pot and another to the outside of the crucible. Each of these tubes contained two thermocouples and one couple from each tube was connected to a coil of a double-coil mirror galvanometer, so that equal currents in each coil acted against each other and produced no deflection. The reflected beam of light fell on two selenium cells connected in a circuit to furnish a small amplification and actuate an electro-pneumatic controller which governed the power supplied to the tungsten heaters. The operation of the controller was thus determined by the currents flowing from the thermocouples, but owing to the change with temperature of the resistance of the thermocouple leads in the hot zones of the apparatus, this was not the same as control by the thermocouple voltage. To correct for this, the other thermocouples from the two alumina tubes were connected to a continuously driven rotary switch which connected them in turn once every minute, for a ¼ min, to a potentiometer backing off multiples of 100μV, the remaining voltage operating an amplifier with a recording unit.

The chart of this unit was watched and whenever necessary the index of the electro-pneumatic controller was adjusted to keep the mean deviation as nearly zero as possible. Normally the reading of the thermocouple attached to the pot could be held within ± 3μV of that attached to the crucible and for considerable periods would be within ± 2μV. Either one or two thermocouples indicating temperature of the specimen were also connected to the automatic switch, so that a record of specimen temperature against time was obtained.

The thermocouple terminals just outside the bell were immediately connected to earth by condensers and by screened cable to the potentiometer and other apparatus. In spite of these precautions, however, sufficient a.c. current was still present in the thermocouple leads to prevent an amplifier with a 50-cycle reed operating satisfactorily from them. A galvanometer amplifier was therefore used to operate the recorder which indicated specimen, crucible, and enclosure temperatures. The double-coil mirror galvanometer operated by the temperature balance thermocouples separated these circuits electrically from the selenium amplifier, actuated by its reflected light beam, and from the associated circuit of the 50-cycle reed amplifier of the electro-pneumatic controller governing the power supplied to the tungsten heaters. At high temperatures it was necessary to earth the specimen to obtain adequate shielding for the thermocouple which recorded specimen temperature. For steel this was done by using a fine iron wire together with a small-diameter Nernst filament rod, which projected through a close-fitting hole in the lid of the crucible and connected to a platinum wire. When the iron wire melted the Nernst filament was sufficiently conducting to maintain the earth connection.

To avoid contamination of the thermocouples, the sheaths were of impervious recrystallized alumina, and where they passed between the pot and the refractory blocks holding the tungsten heaters they were protected from deposits of tungsten and tungsten oxides by passing through holes in small blocks of alumina. As the trajectories of the vapour molecules were straight lines, small curved metal sheets placed partly around the exits of pumping holes in the refractory blocks were useful in deflecting vapour deposits from harmful positions. Since the thermocouples were some hours at high temperatures in the course of measurements on one specimen, it was very important to use inside the alumina sheaths sufficiently long close-fitting alumina separator tubes around each limb of a thermocouple to extend without a joint from the hot junction to the cold open end of the tube. Separator tubes in short lengths allowed deposits of rhodium and platinum evaporated from the hot junction region to form on the limbs of the thermocouple where gaps in the separator tubes occurred in a region of substantial temperature gradient. These deposits then acted as subsidiary hot junctions and might produce e.m.f.'s vitiating the thermocouple readings. To obtain as nearly similar thermocouples as possible for maintaining the temperature balance, a length of 5% rhodium–platinum wire was placed alongside a similar length of 20% wire, then each length was cut at the middle and pairs from the four adjacent cut ends were welded to form the two hot junctions.

METHOD OF EXPERIMENT

As pointed out by Awbery and Griffiths,[1] it is desirable to use the adiabatic method of thermal measurement as a continuous process because of the time necessary to establish the proper temperature gradients. There is at the beginning of an experiment a rising temperature produced in the internal heater and a temperature wave passes outwards. Because of the vacuum, heat transfer between the heater and the surrounding specimen material and between the specimen and the crucible is mainly by radiation until the specimen is molten. Differences of temperature are built up which, in a specimen of low emissivity, may need taking into account. When the emissivity is not too low and the variation of thermal capacity with temperature not too rapid, after about 20 min the temperature/time graph for the crucible is closely parallel to that for the speci-

men. As the temperature rises further the efficiency of radiation transfer increases and the temperature difference between specimen and crucible gradually diminishes.

Therefore, particularly at high temperatures, there was often negligible difference between the curves of temperature/time indicated by the specimen and crucible thermocouples, but except when the specimen was molten more ripple was associated with the crucible thermocouple curve, since the rate of temperature rise in the crucible due to the constant wattage supplied to the internal heater was more affected by superimposed fluctuations due to changes in the rate of increase of the controlled enclosure temperature. There was also an effect on the specimen and crucible couple curves, more pronounced near the beginning of a run, due to the initial rise of temperature of the internal heater to a maximum difference above the specimen, followed by the gradual decline in the difference with increasing temperature. To allow for the thermal capacity of the crucible and heater and the effective capacity due to the thermocouple tubes and the radiation screens, a blank run was made without the specimen in position and preferably at about the same rate of rise of temperature as with the specimen, to keep as nearly as possible the same conditions in the apparatus with regard to temperature gradients.

As about two days were needed for pumping down and degassing, the temperature before beginning a run usually would have been nearly stationary for some time and brought to about 400° C. A check could be made by putting the apparatus on automatic control with no current supplied to the internal heater to see if the temperature was maintained nearly stationary, and this was normally the case. At the end of a run the same check could be made and if, as usually happened at high temperatures, a slow fall in temperature occurred, this was allowed for in working out the results. It was arranged to make the first run stopping a little short of the melting temperature, the temperature balance then being checked. After a subsequent run passing through the region of melting, during which the temperature might be nearly stationary for about 2 h, the balance was again checked.

On the recorder chart tracing thermocouple e.m.f's against a time scale of 1 in./min, 100μV were represented by 20 divisions, the chart being 40 divisions wide. As a division was nearly 0·1 in., eye estimation was possible to about 0·1 division, corresponding to 0·5μV, but movement of the recorder pen was not quite proportional to the e.m.f. applied to the amplifier and, although the chart graduations were purposely not quite linearly divided in an attempt to compensate, errors up to about 2μV could arise because of this.

With a specimen of low emissivity, a note was made of the crucible temperature increase $(\theta^1_c - \theta_c)$ occurring at the same time as the specimen temperature increase $(\theta^1_s - \theta_s)$, both being measured on the recording chart for the full crucible. From the recording chart made for the empty crucible, $(dH_c/dt)/(d\theta_c/dt)$ the rate of heat supply needed for the rate of temperature increase was measured and the appropriate number of joules $(H^1_c - H_c)$ thereby found to correspond to $(\theta^1_c - \theta_c)$ was subtracted from the number of joules $(H^1_s - H_s)$ corresponding to $(\theta^1_s - \theta_s)$.

Not more than 60 W were usually supplied to the internal heater and, to measure the power taken, rhodium–platinum potential leads were welded to the heater current leads close to the beginning of the heater coils. It was necessary to allow for measuring instrument losses, which amounted to 1% or 2%, and the normal method for determining these involves short-circuiting the load. As the load was inside the vacuum enclosure, the resistances of the heater and leads at various temperatures were obtained from Wheatstone bridge measurements on the current and voltage terminals just outside the vacuum enclosure and subsequently, by means of throw-over switches, an outside dummy circuit made of adjustable resistances set to similar values was substituted for the circuit inside the bell. The usual method of obtaining instrument losses was then applied.

Sources of Error

These were principally:

(i) Non-uniformity of temperature over the crucible forming the inner enclosure
(ii) Non-uniformity of temperature over the pot forming the outer enclosure
(iii) Average temperature over the inner enclosure being unequal to the average temperature over the outer enclosure. This was mainly due to the average temperature over the inner enclosure being unequal to the temperature at the region of attachment of the balancing thermocouple, but partly also to the same thing with regard to the outer enclosure and its thermocouples, and partly to imperfection of balance between the thermocouple e.m.f.'s of the two enclosures.
(iv) Heat transfer along thermocouple sheaths and wires, internal heater leads, and crucible supports, and by radiation through crevices in the screens
(v) Inaccurate measurement of wattage to internal heater
(vi) Inaccuracy of recorder-pen movement and of the recorder time scale
(vii) Evaporation of specimen
(viii) Electrical leakage to the thermocouple circuits.

A check made by using six thermocouples around the outer enclosure showed that radiation was very effective in equalizing the temperature and, provided that the power dissipated by the tungsten heaters was distributed as evenly as possible between the six faces of the surrounding rectangular enclosure, error on this account would usually be unimportant, except when the apparatus was working near the lower limit of its temperature range. Non-uniformity of temperature around the crucible was much more serious and, if the latter was only half-filled by a specimen, results could obviously be in error. The necessity for having the test-tube-shaped alumina tube, containing the internal heater, projecting slightly through a hole in the crucible lid made this region hotter than the side of the crucible, and there was also the possibility of a hot spot at the centre of the base of the crucible. The heater windings were therefore kept away from the ends of the tube, the

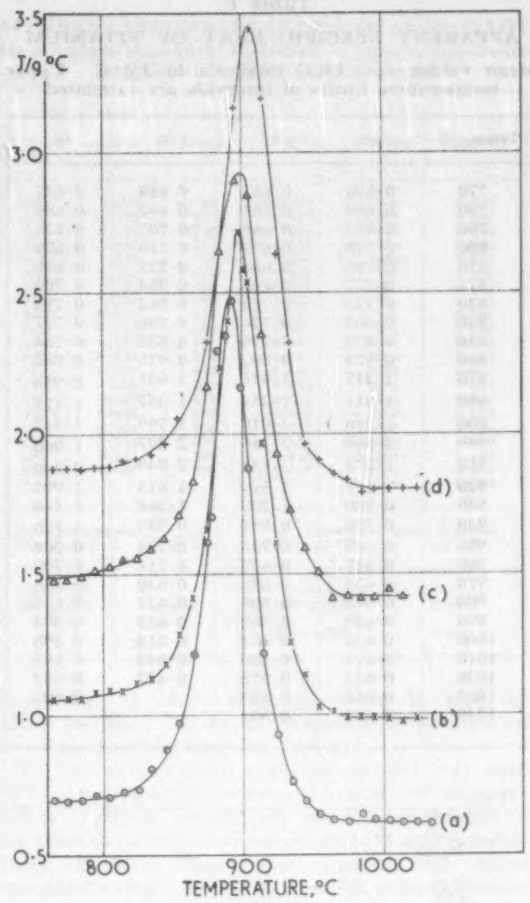
mouth of which was almost completely plugged with alumina baked into it.

The distribution of temperature in a vertical direction at the side of the crucible was investigated by arranging so that the hot junction of the crucible thermocouple operating the recorder could be raised and lowered in its sheath by rotating a shaft through a vacuum seal during an experiment. At a crucible temperature in the region of 1000° C the thermocouple, when in e.m.f. balance at its normal position about halfway up the side of the crucible, was from 1° to 2° C low when at either the top or bottom of the crucible, if the heater was on at the usual rate.

From measurements made with the apparatus set to run automatically about 8° C out of balance, the rate of fall of temperature of the specimen at 1000° C corresponded to a heat loss of about ½W/° C out of balance. At a usual heater rate of about 45 W, an error of 1°C in the balance would therefore produce an error of about 1%. This would apply when the whole of the crucible surface-area was out of balance by 1°C. The area of the projecting portion of the internal heater was about 5 cm² or 2% of the crucible area, so that with this projecting portion 60° C in excess an error of the order of 1% would arise. Only part of this would be compensated on subtraction of the figures for the empty crucible, since the excess temperature of the projecting portion of the heater was then less.

Some uncertainty arises concerning the destination of heat developed in the leads to the internal heater and the extent of heat transfer along the leads. Since the temperature of the wires in the heater will be above that of the crucible when the temperature is rising, these two effects will fortunately be opposite in direction. Provided that the effective temperatures over the area concerned really correspond to the thermocouple e.m.f's, the unbalance of temperature of the crucible and enclosure will not be serious, since the e.m.f's from the couples are remarkably well balanced with the aid of the electro-pneumatic controller. Without this instrument and with manual control alone, it would appear to be quite hopeless to attempt to obtain a satisfactory balance at high temperatures. More than 60 W is seldom needed for the internal heater, so that a transfer of 1 W, if not allowed for, between the inner and outer enclosures leads to an error of nearly 2%, while in the region of 1600° C the power dissipated in the tungsten heaters may be about 5 kW.

To support the weight of the crucible and specimen, three thin-walled hollow cones of alumina stand on the base of the pot and project through holes in the three radiation screens. The tips of the cones make only a very small area of contact with the crucible, but some unwanted heat transfer may occur here and along the alumina sheaths of the specimen and crucible thermocouples. Evaporation of the specimen could be important but fortunately a crucible with a well-fitting lid effectively checks evaporation at low pressures. The inside of a crucible can become well covered with metal volatilized from a solid specimen and, after a specimen has been molten, the metal usually adhering to the underside of the lid indicates that plenty of vaporization has occurred in the crucible. Any appreciable escape of metal from the crucible must, however, cause a loss of heat producing a noticeable rate of fall of temperature on 'line out'. The heat transfer indicated by the line out was allowed for when deducing the results so that, when the line out rates were not too large or too different at the beginning and end of an experiment, error on this account should be mostly eliminated.



Vertical scale successively translated by 0·4J/g° C for each set of measurements in order of experiment

Fig. 3—Mean apparent specific heat of titanium at transition

Titanium

A specimen of commercial titanium weighing 1022 g was taken four times through the temperature range 590–1080° C to study the apparent specific heat in the region of the transition from close-packed hexagonal α to body-centred cubic β form. As shown in Fig. 3 the transition peak moved to successively higher temperatures during the recordings. This shift was attributed to the effect of gas taken up by the specimen during the progress of the work, although a vacuum better than 0·1μ was maintained throughout, apart from the initial degassing period before

Table I

APPARENT SPECIFIC HEAT OF TITANIUM

Mean values over 10° C intervals in J/g° C. Upper temperature limits of intervals are tabulated

Temp., ° C	(a)	(b)	(c)	(d)
770	0·696	0·654	0·688	0·677
780	0·689	0·651	0·692	0·680
790	0·692	0·658	0·707	0·676
800	0·710	0·673	0·718	0·676
810	0·705	0·686	0·723	0·679
820	0·727	0·683	0·754	0·700
830	0·733	0·710	0·764	0·712
840	0·803	0·726	0·796	0·727
850	0·870	0·776	0·839	0·764
860	0·978	0·882	0·916	0·852
870	1·217	1·013	1·031	0·915
880	1·611	1·254	1·357	1·123
890	2·270	2·010	1·798	1·447
900	2·369	2·140	2·207	1·960
910	1·874	2·138	2·049	2·240
920	1·217	1·569	1·615	1·992
930	0·930	1·208	1·264	1·440
940	0·756	0·850	0·939	1·120
950	0·689	0·735	0·794	0·764
960	0·647	0·622	0·711	0·709
970	0·624	0·608	0·620	0·658
980	0·615	0·588	0·624	0·635
990	0·639	0·587	0·613	0·594
1000	0·620	0·584	0·614	0·598
1010	0·613	0·580	0·642	0·603
1020	0·612	0·575	0·622	0·602
1030	0·613	0·583		0·606
1040	0·612	0·594		

Table II

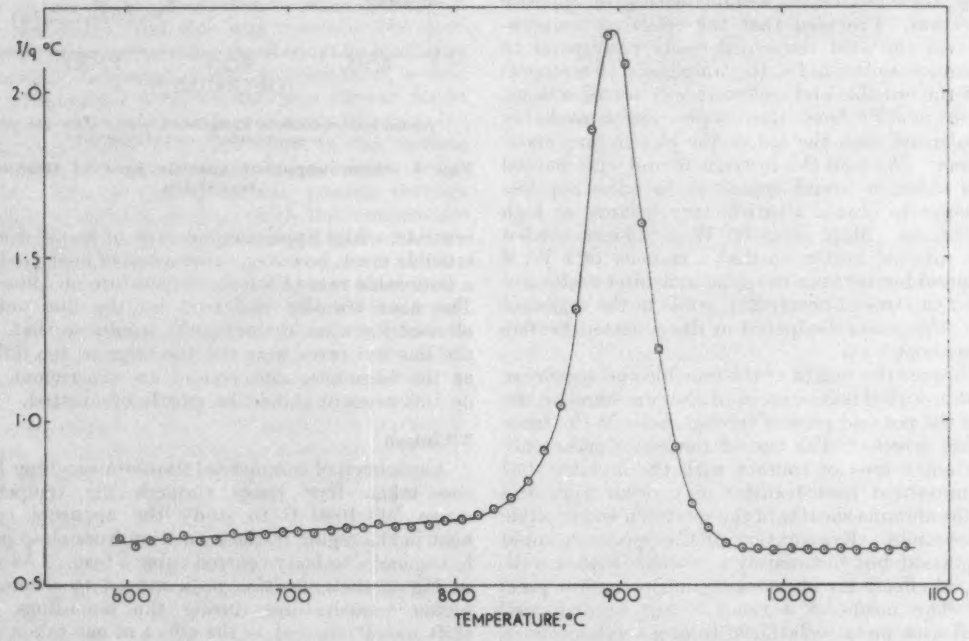
APPARENT SPECIFIC HEAT OF TITANIUM

Actual values at tabulated temperatures near transition peak in J/g° C

(a)		(b)		(c)	
Temp., °C	Specific Heat	Temp., °C	Specific Heat	Temp., °C	Specific Heat
878	1·700	886	1·825	875	1·370
883·6	2·292	892	1·999	885	1·850
888	2·346	898·6	2·322	895	2·108
893·4	2·470	901	2·188	900	2·123
899	2·160	905	2·140	905	2·059
				915	1·560
				925	1·136
				935	0·938

the recordings, during which the specimen was brought to about 400° C. The gas absorbed would be almost entirely oxygen, for which titanium is an effective ' getter ', and about $\frac{1}{2}$ at-% would be enough to produce the observed shift in the direction of higher temperature.[4]

Values of the mean apparent specific heat over 10° C intervals are plotted against the mean temperatures of the intervals, except that near the upper portion



Mean of four sets of measurements

Fig. 4—Mean apparent specific heat of titanium over 10° C intervals

Table III

APPARENT SPECIFIC HEAT OF TITANIUM

Mean values over 10° C intervals. Mean of four experiments

Temp., °C, at upper limit of 10°C interval	Experimental Points, J/g° C	Smoothed Curve, J/g° C	Temp., °C, at upper limit of 10° C interval	Experimental Points, J/g° C	Smoothed Curve, J/g° C
600	0·644	0·635	850	0·812	0·813
610	0·622	0·637	860	0·907	0·897
620	0·638	0·639	870	1·044	1·053
630	0·649	0·642	880	1·336	1·336
640	0·652	0·644	890	1·881	1·881
650	0·639	0·647	900	2·169	2·169
660	0·646	0·649	910	2·075	2·075
670	0·657	0·652	920	1·598	1·598
680	0·652	0·655	930	1·211	1·211
690	0·655	0·658	940	0·916	0·916
700	0·664	0·660	950	0·746	0·756
710	0·663	0·663	960	0·672	0·655
720	0·663	0·666	970	0·627	0·627
730	0·668	0·669	980	0·615	0·615
740	0·676	0·672	990	0·607	0·610
750	0·676	0·675	1000	0·606	0·607
760	0·686	0·678	1010	0·609	0·605
770	0·679	0·681	1020	0·603	0·604
780	0·678	0·685	1030	0·601	0·604
790	0·683	0·689	1040	0·603	0·604
800	0·694	0·694	1050	0·601	0·604
810	0·699	0·699	1060	0·611	0·604
820	0·710	0·710	1070	0·601	0·605
830	0·730	0·730	1080	0·608	0·605
840	0·763	0·763			

of the peak, where a significant difference may occur between the mean value over a 10° C interval and the actual value at the mean temperature of the interval, some of the mean values, shown bracketed in Table I, are replaced by actual values from Table II to show more precisely the shape of the peak. Curves *a* and *b* were obtained from readings of a thermocouple encased in an alumina sheath and inserted in a hole in the specimen close to its outer cylindrical surface, the hole being bored parallel to the cylinder axis. Curves *c* and *d* were obtained from readings of a bare thermocouple pegged into a small hole in the specimen close to the inner cylindrical surface next to the central alumina tube forming the wall of the internal heater. At the heating rate used, (about 2° C/min), this couple gave readings between 2° and 3° C in advance of those from the sheathed couple. It follows that the broad base of about 140° C to the peak is not due in any appreciable measure to thermal lag, but is a property of the specimen such as would be occasioned by impurities. A likely impurity would be iron, of which less than 1% would be enough to produce an $\alpha + \beta$ phase of the observed extent.[5]

Table V

APPARENT SPECIFIC HEAT OF A 44%Cr–Fe ALLOY

Mean values over 10° C intervals. Upper temperature limits of the intervals are tabulated

(a) Alpha phase

Temp., °C	J/g° C	Temp., °C	J/g° C	Temp., °C	J/g° C
500	0·689	700	0·639	900	0·640
510	0·725	710	0·639	910	0·642
520	0·794	720	0·639	920	0·644
530	0·886	730	0·638	930	0·646
540	1·028	740	0·637	940	0·648
550	1·182	750	0·637	950	0·650
560	1·219	760	0·637	960	0·652
570	1·034	770	0·637	970	0·655
580	0·864	780	0·637	980	0·658
590	0·762	790	0·637	990	0·660
600	0·697	800	0·636	1000	0·662
610	0·671	810	0·635	1010	0·664
620	0·659	820	0·634	1020	0·667
630	0·652	830	0·633	1030	0·670
640	0·649	840	0·633	1040	0·672
650	0·646	850	0·633	1050	0·674
660	0·644	860	0·633	1060	0·676
670	0·643	870	0·634	1070	0·678
680	0·641	880	0·636	1080	0·680
690	0·640	890	0·637	1090	0·682
				1100	0·684

(b) Sigma phase Temp., °C	J/g° C	(c) Transition sigma to alpha Temp., °C	J/g° C
Interval: 600 to 830	0·624	Interval: 830 to 840	0·669
		840 to 850	3·341

In Fig. 4, the mean apparent specific heat over 10° C obtained as the average of four sets of measurements is plotted against the mean temperatures of the intervals over the full temperature range recorded. Table III shows these values, together with values smoothed so that the first and second order difference curves are smooth and the summation giving the enthalpy is not appreciably affected. The limits of experimental error are estimated to be about $\pm 5\%$. If the heat of transition is estimated by considering the temperature interval from 800° to 980° C and subtracting from the integral of the thermal capacity over this range 180 times the mean of the first and last values in the interval, the results are 77·55, 77·32,

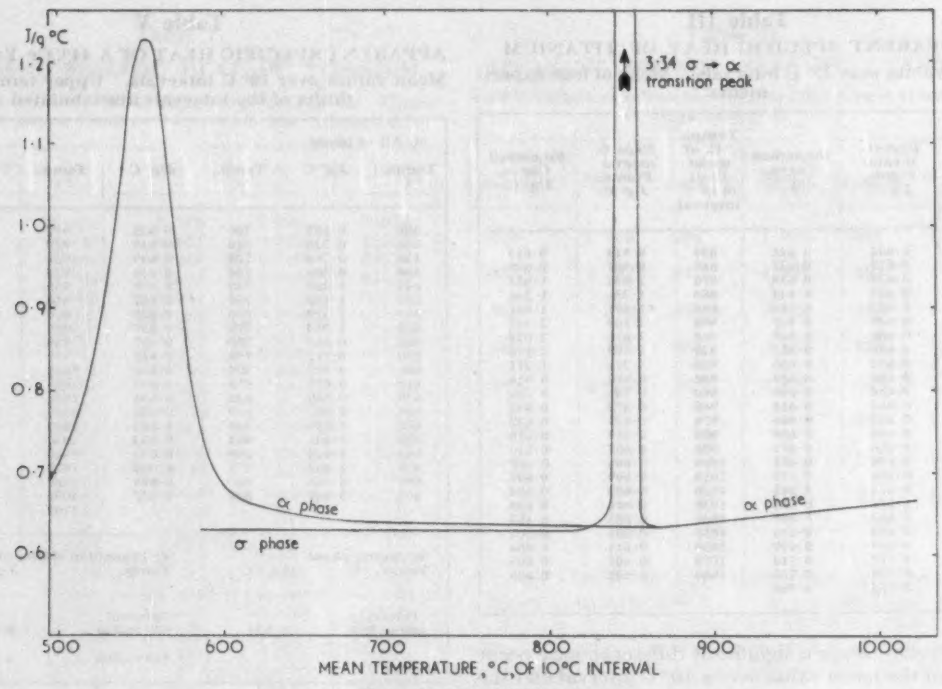
Table IV

TITANIUM TRANSITION $\alpha \rightarrow \beta$

Material	Reference	Temperature of Transition Peak, °C			Width of Transition	Latent Heat of Transition
		1200° C/min	180° C/min	Slow e.g. 2° C/min	C	cal/g-atom
N.J.Z.	Schofield[6]	891	874	871*	22	814
I.C.I.	Schofield[6]	905	886	883*	50	811
Philips (Eindhoven)	Jaeger[8] *et al.*	...	...	880 to 906	88	950†
Philips (Eindhoven)	McQuillan[9]	...	...	882·5	...	670
Commercial	This paper	...	...	892 to 906	140 to 180	880

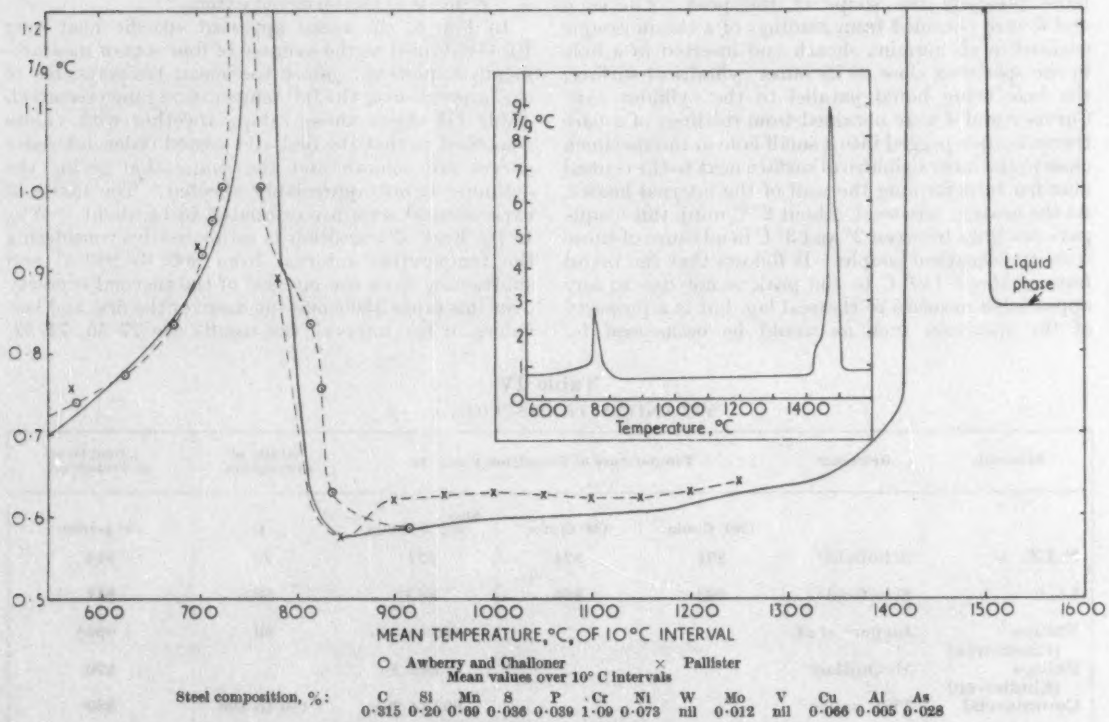
* Extrapolated

† Estimated by Kelley[7]



Mean values over 10° C intervals

Fig. 5—Specific heat of 44% Cr–Fe alloy



○ Awberry and Challoner × Pallister
Mean values over 10° C intervals

Steel composition, %:	C	Si	Mn	S	P	Cr	Ni	W	Mo	V	Cu	Al	As
	0·315	0·20	0·69	0·036	0·039	1·09	0·073	nil	0·012	nil	0·066	0·005	0·028

Fig. 6—Specific heat of alloy steel no. 19, composition as shown

Table VI

APPARENT SPECIFIC HEAT OF AN ALLOY STEEL, J/g° C

Mean values over 10° C intervals. Upper temperature limits of intervals are tabulated

Analysis, wt-%

C	Si	Mn	S	P	Cr	Ni	W	Mo	V	Cu	Al	As
0·315	0·20	0·69	0·036	0·039	1·09	0·073	Nil	0·012	Nil	0·066	0·005	0·028

Annealed at 860° C

Temp., ° C	Specific Heat	Temp., ° C	Specific Heat	Temp., ° C	Specific Heat	Temp., ° C	Specific Heat
550	0·697	820	0·631	1090	0·598	1360	0·656
560	0·707	830	0·592	1100	0·599	1370	0·664
570	0·717	840	0·580	1110	0·599	1380	0·675
580	0·726	850	0·577	1120	0·599	1390	0·686
590	0·736	860	0·576	1130	0·600	1400	0·699
600	0·747	870	0·577	1140	0·601	1410	0·712
610	0·757	880	0·578	1150	0·602	1420	0·730
620	0·768	890	0·579	1160	0·603	1430	1·367
630	0·779	900	0·580	1170	0·604	1440	1·717
640	0·791	910	0·581	1180	0·606	1450	1·811
650	0·803	920	0·582	1190	0·608	1460	2·610
660	0·815	930	0·584	1200	0·610	1470	3·896
670	0·828	940	0·586	1210	0·613	1480	8·882
680	0·843	950	0·588	1220	0·616	1490	5·830
690	0·858	960	0·590	1230	0·619	1500	4·826
700	0·875	970	0·591	1240	0·622	1510	1·060
710	0·896	980	0·592	1250	0·624	1520	0·856
720	0·923	990	0·593	1260	0·627	1530	0·856
730	0·959	1000	0·594	1270	0·629	1540	0·856
740	1·009	1010	0·594	1280	0·631	1550	0·856
750	1·075	1020	0·595	1290	0·632	1560	0·856
760	2·764	1030	0·596	1300	0·633	1570	0·856
770	2·159	1040	0·596	1310	0·635	1580	0·856
780	1·277	1050	0·596	1320	0·638	1590	0·856
790	0·912	1060	0·597	1330	0·641	1600	0·856
800	0·863	1070	0·597	1340	0·645		
810	0·713	1080	0·598	1350	0·650		

76·78, and 76·11 J/g corresponding to columns *a*, *b*, *c*, and *d* of Table I, so giving a mean value close to 77 J/g or 880 cal/g-atom.

Table IV compares available data on the transition heat. Schofield[6] used a rapid-heating method with specimens of material supplied by the New Jersey Zinc Co. and by I.C.I. The rates of temperature rise shown are means of the rates before and after the transition, which was found to be unaffected in width by the rate of heating. Kelley[7] deduced the transition heat from the specific heats of the α and β phases measured by Jaeger, Rosenbohm and Fonteyne,[8] who used a drop method. McQuillan[9] derived a value from measurements on the titanium–hydrogen system.

44% Chromium–Iron Alloy

This alloy has a σ to α transition on heating that is slow to reverse on cooling. A recording was made to include the transition and then, after cooling at 2–3° C/min, the specimen was reheated over the temperature range 500–1100° C. No trace of a σ to α transition heat was then observed, so that in the time that the temperature was below the transition point, no appreciable reversal from α to σ had occurred. With two or three exceptions, the values deduced for successive 10° C intervals fluctuated within ± 3% of the curves shown in Fig. 5, which are drawn so as to keep unaltered the enthalpies obtained by summation. The mean specific heats over 10° C intervals in J/g ° C obtained from the curves are set in Table V against the upper temperature limits of the intervals.

The heat of transition was obtained as follows: the specific heats at the beginning and end of the 20° C interval that included the transition were 0·624 and 0·630 respectively and the mean value of 0·627 corresponded to 12·54 J/g for the 20° C interval. The apparent mean specific heats at the transition were 0·669 over the first 10° C interval and 3·341 over the second, giving 6·69 J/g and 33·41 J/g respectively. This total heat intake of 40·10 J/g, minus 12·54 J/g because of the true specific heat, gave the transition heat as 27·56 J/g or to within the available accuracy 27½ J/g.

Estimates of the transition heat of a 44·7% Cr–Fe alloy have been made by Martens and Duwez.[10] At a heating rate of 15° C/s they found a thermal arrest at about 870° C of duration 2·4 s, from which a transition heat of 342 cal/mol was deduced. They also compared a heating-temperature/time curve for the alloy with one obtained for pure iron under identical conditions. The thermal arrest time for the alloy was 1·8 times as long as that for the iron and, taking 203 cal/mol for the α to γ iron transition, they obtained 365 cal/mol for the σ to α change.

The 27½ J/g found in the present work equals

356 cal/mol. The transition occurred at 842° C with a heating rate just before it of about 2° C/min.

Alloy Steel no. 19

This was a specimen of alloy steel cut from a bar of the same material as that reported on as no. 19 in 1946[11] up to 1250° C. The analysis was as shown in Table VI.

The specimen, weighing 1809·0 g, was heated continuously with the internal heater at a constant rate of 40 W up to 1210° C during one day and left at about 1000° C overnight. The following day the record was continued through the melt and up to 1600° C at a rate of 50 W. At the end of each run a check was made that, when the internal heater was switched off, the temperature became nearly constant. During the melting of the steel an appreciable evolution of gas took place, the pressure in the calorimeter rising to nearly 3μ in the initial stages and to nearly 2μ afterwards. Mostly the pressure was in the range 0·05–0·5μ.

The records gave a continuous cover of the temperature range so that the specific heat could be deduced at any desired temperature, but it was thought the most useful to tabulate the mean specific heat over a short temperature interval, i.e. 10° C, so that total heats could be obtained by simple addition. In Table VI the figure for the specific heat refers to the 10° C range having as its upper limit the corresponding figure for the temperature.

The latent heat of melting of the steel may be evaluated approximately by interpolating over the range 1400–1520° C for the true specific heat. If the values given in the table at 1410° C (range 1400–1410° C) and 1520° C are taken as true specific heats and linear interpolation is used, the heat absorbed by the steel as true specific heat in the range 1400–1520° C is $\frac{1}{2}(0{\cdot}712 + 0{\cdot}856) \times (1520–1400)$, i.e. 94 J/g. Adding the apparent specific heat values in the table from 1410° to 1520° C inclusive gives 343 J/g, leaving a difference of 249 J/g or 60 cal/g to be interpreted as being due to latent heat of melting or transition. If tangents to the record are taken, instead of chords over 10° C, the small hump at 1440° C near the base of the melting peak in the small-scale curve of Fig. 6 is just resolvable as a separate peak and so indicates a transition heat.

For comparison, the value of the latent heat of melting of a 4% silicon transformer steel obtained by Oberhoffer and Grosse,[12] using a good version of the drop method, was 62·21 cal/g, the temperature range over which melting occurred in that case being only 12° C.

Acknowledgments

The work described above has been carried out as part of the research programme of the National Physical Laboratory, except for that on the alloy steel, which was undertaken on behalf of the Thermal Treatment Committee of the British Iron and Steel Research Association, who provided financial support and to whom acknowledgments are due for permission to publish the results.

The author is much indebted to Dr. V. H. Stott of the Metallurgy Division, N.P.L., for invaluable help in making all the specially shaped ceramics needed, and to Mr. D. G. Moss and Mr. D. J. Hamblin of the Physics Division, N.P.L., for much skilful assistance in the development and operation of the calorimeter.

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Deep Drawing Research

At a luncheon held on 23rd April, Mr. J. Ryan, C.B.E., M.C., President of the Institute of Sheet Metal Engineering, announced the inauguration of a British Deep Drawing Research Group, whose function will be to co-ordinate all research and development in the fields of deep drawing and allied processes. The new venture is sponsored by B.I.S.R.A., the British Non-Ferrous Metals Research Association, the Institute of Sheet Metal Engineering, and the Production Engineering Research Association; it is to be administered by a Joint Research Committee of these organizations, under under the chairmanship of Mr. G. Murray (The Pressed Steel Co., Ltd.).

The new Group will effect liaison with similar bodies overseas through the International Deep Drawing Research Group, which was set up in 1957 (*see J.I.S.I.*, 1957, vol. 187, Oct., p. 146). Further information may be obtained from the Honorary Secretary, British Deep Drawing Research Group, The Institute of Sheet Metal Engineering, John Adam House, Adelphi, London W.C.2.

Colloquium on Trace Elements

A Colloquium on "Arsenic, Copper, and other Trace Elements in Ores, Iron, and Steel" is being organized by the Metallurgical Institute and the Department of Mining and Metallurgy of the University of Ljubljana, Yugoslavia. It will be held from 20th to 23rd September at Portorose, in co-operation with the Society of Mining and Metallurgical Engineers and Technicians of the People's Republic of Slovenia and the Yugoslav Iron and Steelworks Association. Papers are being contributed from Belgium, France, and Germany as well as the host country. Further details may be obtained from the Metalurški Institutet, Jamova cesta 3, Ljubljana.

The Effect of Some Common Alloying Elements on the Volume Change at Ac_3 of a 0·35% Carbon Steel

By A. S. Kenneford, M.Sc., F.I.M., Assoc.I.Mech.E.

SYNOPSIS

The effect of some of the elements commonly used in alloy steels on the volume change at the Ac_3 temperature has been investigated dilatometrically. It has been shown that silicon and molybdenum, and possibly also vanadium, reduce the volume change at Ac_3, whereas manganese, chromium, nickel, and cobalt have the opposite effect. These volume changes are important in that they can affect those taking place at the M_s temperature, and consequently also the susceptibility of a steel to cracking on quenching. 1502

INTRODUCTION

THE SUBJECT of volume changes in steel is an interesting one which appears, at any rate from the published work, to have been almost completely neglected until a study was begun some years ago in the Armament Research and Development Establishment. This neglect is all the more surprising in that a large number of workers have used dilatometric measurements for the determination of phase changes during the plotting of thermal equilibrium diagrams, and for the measurement of coefficients of expansion over various temperature ranges.

Interest in volume changes at the $\alpha \rightarrow \gamma$ transformation was aroused by two distinct, but possibly related, phenomena, namely

(*a*) cracking of steel during quenching
(*b*) surface cracking induced by repeated heating and cooling.[1]

It would seem possible that the volume change at Ac_3 has a considerable influence on the susceptibility of a steel to crack on quenching, in that it can directly affect the volume change (expansion) at the M_s temperature on rapid cooling. Figure 1 illustrates how this may occur, and shows also that two steels of different composition may have the same M_s temperature, but may also undergo considerably different volume changes on the formation of martensite.

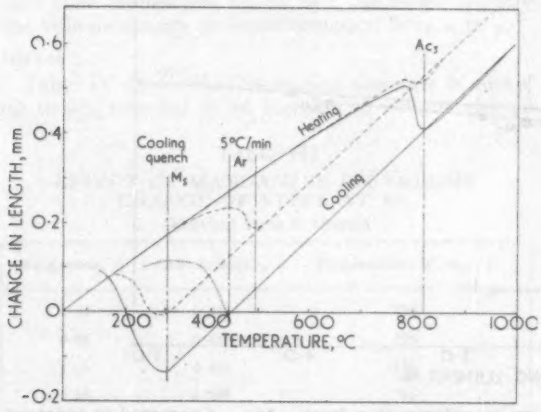

Fig. 1 — Effect of volume change at Ac_3 on that at M_s

MATERIALS USED

The steels used for this investigation were in the form of ½-in. dia. rod, hot-forged from small h.f. furnace casts weighing about 18 lb. They comprised eight series with major alloying elements as follows: carbon, silicon, manganese, nickel, chromium, cobalt, molybdenum, and vanadium.

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Mr. Kenneford is with the Ministry of Supply, Armament Research and Development Establishment, Woolwich.

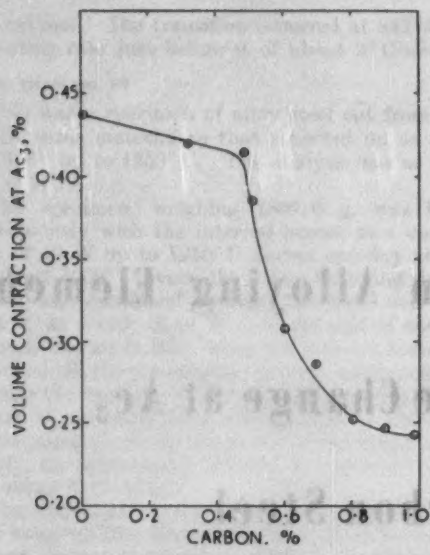

Fig. 2—Effect of carbon on volume contraction of transformation from α to γ. Corrected to constant temperature of 780° C

The actual compositions of the various steels are not reproduced as they have been given in a previous paper in this *Journal*.[2]

MEASUREMENT OF VOLUME CHANGES

The measurement of the volume changes at Ac_3 and the temperatures at which the phase change took place was accomplished by means of a Leitz universal dilatometer using a heating and cooling rate of 5° C/min with a maximum temperature of about 1000° C. The magnification used was × 250, and heating and cooling took place in a vacuum of 5×10^{-3} mm Hg, which was sufficient to prevent any undue oxidation of the test specimen.

Table I
EFFECT OF CARBON ON VOLUME CHANGE OF STEEL AT Ac_3
Heating rate 5° C/min

Carbon, %	Contraction, %	Temperature of Ac_3, ° C
0·32	0·419	780
0·49	0·443	742
0·51	0·419	733
0·61	0·347	725
0·70	0·329	719
0·81	0·299	713
0·90	0·294	714
0·99	0·289	714

The contraction in length of the specimen was measured by subtracting its length at the end of the phase change from that at the beginning of the change. This length change was then multiplied by 3 and called a volume change. Such a calculation assumes that the specimen expands or contracts equally in all directions, and may not be entirely justified, though it is considered that the method is suitable for purposes of comparison. Another difficulty which arises from measurements made on a variety of steels is that the Ac_3 temperature is altered considerably by alloy additions, and therefore measurements made directly from dilatometer diagrams are not strictly comparable with one another unless the contraction is corrected to some arbitrary temperature. In the present discussion, the actual measured values obtained are presented in tabular form, whilst the values corrected to 780° C (to enable direct comparison with the steel containing 0·32% carbon) are presented graphically in Figs. 2 and 3.

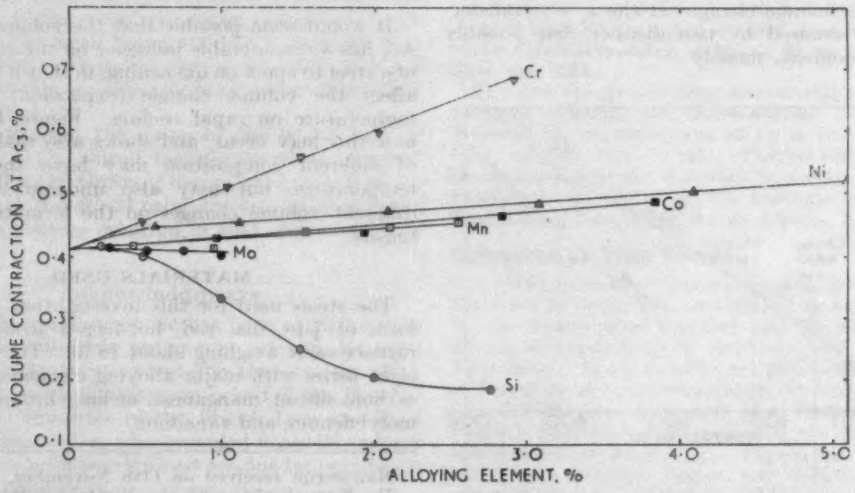

Fig. 3—Effect of alloying elements on volume contraction on transformation from α to γ. Corrected to constant temperature of 780° C

Table II

EFFECT OF SILICON ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Silicon, %	Contraction, %	Temperature of Ac_3, ° C
0·2	0·419	780
0·45	0·359	840
1·0	0·262	887
1·51	0·168	906
1·98	0·090	951
2·76	0·066	957

EFFECT OF ALLOY ELEMENTS

Carbon

The effect of increasing amounts of carbon on the volume change as measured and corrected to 780° C is shown in Table I and Fig. 2 respectively.

These results show that increasing the carbon content of a steel from 0·32% to 0·51% has practically no effect on the volume change at Ac_3, but that there is a rapid diminution between 0·51% and 0·81% carbon, followed by a small effect at carbon contents above that of the eutectoid.

Silicon

Table II shows the effect of increasing silicon content in the steels used. This effect was remarkable in that silicon lowered considerably the volume contraction occurring at the $\alpha \rightarrow \gamma$ phase change, until with a silicon content of 2·75% the volume contraction was only 0·066%, compared with 0·419% for a similar steel containing 0·2% silicon. At present there would not appear to be any explanation of this effect, though silicon in solution in α-iron is known to contract the lattice. Its effect on the γ lattice has not apparently been investigated, and it may be that silicon does not contract the γ lattice to the same extent as it does the α, thus reducing the net volume change on transformation from α to γ.

Manganese

The results obtained by increasing the manganese content of the steel are given in Table III, and indicate that manganese up to 2½% increased slightly the volume change on transformation from α to γ.

Nickel

Table IV shows that increasing amounts of nickel up to 5% resulted in an increase in volume change at Ac_3, the increase (uncorrected for temperature variations in Ac_3) being of the order of 35% with 5% nickel.

Table III

EFFECT OF MANGANESE ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Manganese, %	Contraction, %	Temperature of Ac_3, ° C
0·42	0·419	780
0·95	0·419	775
1·55	0·443	776
2·09	0·459	766
2·54	0·467	762

Table IV

EFFECT OF NICKEL ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Nickel, %	Contraction, %	Temperature of Ac_3, ° C
Nil	0·419	780
0·56	0·441	792
1·12	0·456	781
2·08	0·479	771
3·07	0·507	744
4·08	0·534	733
5·10	0·557	724

Chromium

Increasing amounts of chromium in a 0·35% carbon steel resulted in a considerable increase in the volume change on transformation, the measured increase (uncorrected for temperature variations in Ac_3) being about 52% for a 3% chromium addition. The chromium steels tested gave by far the largest volume changes at Ac_3 of all the steels used in these experiments (*see* Table V).

Molybdenum

Molybdenum in amounts up to 1% had little effect either on the volume change of 0·35% carbon steel at the transformation temperature or on the temperature of transformation on heating (Table VI). It did, however, cause a wide separation of the Ar_3 and Ar_1 points on cooling, ferrite beginning to precipitate from the austenite at about 700° C, whilst pearlite formation did not commence until a temperature of about 550° C in a steel containing 0·5% molybdenum. This wide separation of the Ar_3 and Ar_1 points was apparently first recorded by Swinden[3] and seems to be dependent to some extent on the temperature to which the steel is heated above Ac_3 and also on the time of soaking.

In addition to having a slightly reducing effect on the volume change occurring during transformation, molybdenum, in common with silicon, has only a

Table V

EFFECT OF CHROMIUM ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Chromium, %	Contraction, %	Temperature of Ac_3, ° C
Nil	0·419	780
0·48	0·443	795
1·04	0·503	790
1·51	0·551	788
2·02	0·577	801
2·90	0·653	818

Table VI

EFFECT OF MOLYBDENUM ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Molybdenum, %	Contraction, %	Temperature of Ac_3, ° C
Nil	0·419	780
0·26	0·427	765
0·49	0·417	767
0·75	0·420	769
1·00	0·408	772

slightly depressing effect on the M_s temperature. At the same time, however, it has considerable influence on the hardenability of steel. It has been used in conjunction with silicon to produce some experimental steels which are resistant to quench cracking, and are capable of producing a good combination of high tensile strength and ductility after tempering at temperatures up to about 550° C.[4]

Vanadium

As small quantities of vanadium are sometimes used in alloy steels, the effect of this element in amounts up to 0·3% was investigated under heating and cooling conditions identical with those used for the other steels under discussion. Vanadium, however, is a very strong carbide former and, as vanadium carbide is not easily soluble in austenite, it is possible that with slower heating and cooling rates, and a higher maximum temperature, different results would be obtained.

Table VII records the results obtained and indicates that, under the test conditions employed, small amounts of vanadium gave a slight increase in volume change, but that amounts in excess of 0·05% caused a slight progressive lowering in the contraction on transformation.

Cobalt

Although cobalt is not used as an alloying element in low-alloy steels, its effect in amounts up to 4% was investigated since, in common with aluminium, it raises the M_s temperature in steel and also reduces hardenability. The effects of cobalt on the volume change at the transformation temperature are shown in Table VIII, which shows that its behaviour was similar to that of nickel, though less marked.

Table VII

EFFECT OF VANADIUM ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Vanadium, %	Contraction, %	Temperature of Ac_3, ° C
Nil	0·419	780
0·06	0·435	762
0·12	0·443	765
0·20	0·425	775
0·32	0·407	783

Table VIII

EFFECT OF COBALT ON VOLUME CHANGE OF STEEL AT Ac_3

Heating rate 5° C/min

Cobalt, %	Contraction, %	Temperature of Ac_3, ° C
Nil	0·419	780
0·48	0·434	760
0·97	0·442	767
1·92	0·442	776
2·83	0·462	782
3·82	0·480	790

CONCLUSION

The effect of various common alloying elements on the volume change (contraction) on transformation from α to γ in steels containing approximately 0·35 % carbon has been measured dilatometrically using a heating rate of 5° C/min. Of the elements investigated, silicon and molybdenum decrease this volume change, whilst manganese, chromium, nickel, and cobalt increase it. The behaviour of vanadium is uncertain under the conditions used, but this is probably due to the difficulty of dissolving vanadium carbide and to the effective reduction of the carbon content of the steel with the higher percentages of vanadium.

On general grounds, it might have been expected that alloying elements which are ferrite-soluble (silicon, manganese, nickel, and cobalt) would behave similarly to each other, but differently from those which have strong carbide-forming tendencies (chromium, molybdenum, and vanadium). This is not the case, however, nor do elements which show similar characteristics in their various equilibrium diagrams (element–iron systems) behave similarly. For instance, the silicon–iron, molybdenum–iron, and chromium–iron systems all exhibit a closed γ-loop, whereas silicon greatly reduces the transformation volume contraction, molybdenum has only a very slightly reducing effect, and chromium has a strongly increasing effect.

Acknowledgments

The author's thanks are due to Mr. T. Williams who was responsible for much of the experimental work, and to Dr. L. Northcott for the interest shown. Thanks are also due to Mr. W. E. Bardgett of the Research and Development Department, United Steel Companies Ltd., for the supply of the steels used in this work.

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The Corrosion of $2\frac{1}{4}$%Cr–1%Mo Steel by Liquid Bismuth

By G. W. Horsley, M.A., and J. T. Maskrey, B.Sc.

SYNOPSIS

The dynamic corrosion of $2\frac{1}{4}$%Cr–1%Mo silicon-killed steel superheater tubing by liquid bismuth has been studied in thermal convection loops working with maximum temperatures up to 625° C, temperature gradients up to 150° C, and fluid velocities of 3–4 mm/s. Under these conditions the rate at which the steel is corroded by pure bismuth is at least 0·65 in./year. The effect of adding 250–500 p.p.m. Zr to the bismuth as an inhibitor on the corrosion of the steel has been studied. This inhibitor plates out on the steel mainly as a film of zirconium nitride and temporarily prevents attack by bismuth, reducing the corrosion rate to about 0·17 in./year. The film however occasionally spalls off and is not re-formed; under this condition intergranular corrosion of the underlying steel proceeds rapidly. If the steel is heavily nitrided (~ 1% N) its rate of corrosion by inhibited bismuth is reduced to a maximum of 0·010 in./year, the nitride film re-forms if broken, and intergranular penetration is prevented. The effect of pile radiation in BEPO on the corrosion of the steel by inhibited bismuth has also been studied. It has no beneficial effect and may even considerably reduce the corrosion resistance of the steel and the efficiency of the inhibitor.

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A SIGNIFICANT REDUCTION in the corrosion rate of steels by the liquid metals bismuth, lead, mercury, and lithium has been accomplished by the addition of 50–500 p.p.m. of inhibitors such as titanium and zirconium to the liquid metal.[1] Weeks *et al.*[2] have had considerable success with this technique in containing a uranium–bismuth fuel solution in low-chromium steels (2–5%Cr) up to 550° C. The experimental evidence of workers at the Brookhaven National Laboratory, U.S.A., reported by Gurinsky[3] suggests that the corrosion of the steel is prevented by the formation of a zirconium nitride film at the steel/bismuth interface. Frost[4] has discussed the significance of this with regard to using an inhibitor for preventing corrosion of steel components in liquid-metal fuelled reactors. The importance of the findings of the Brookhaven workers to the successful development of economic liquid-metal fuelled reactor systems resulted in an investigation of the inhibitor technique at Harwell in a number of thermal convection loops, the principles and theory of which have been discussed elsewhere.[1]

The objects of these loop experiments were:

(i) To carry out an independent investigation of zirconium as an inhibitor of corrosion of a low-chromium steel by liquid bismuth
(ii) To find out what measures had to be taken to ensure the re-formation of the protective film if the initial film broke away from the steel surface
(iii) To find out the influence of pile radiation on the efficiency of the inhibitor.

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MATERIALS

Steel

In view of the results of Weeks *et al.*[2] and of strength requirements at possible reactor-operating temperatures (450–600°C) the $2\frac{1}{4}$%Cr–1%Mo superheater steel was selected. Cold-drawn steel tubing $\frac{3}{4}$-in. outer dia., 16 s.w.g., was supplied by the Talbot Stead Tube Co., Ltd. Its composition was:

C 0·11%, Si 0·27%, S 0·014%, P 0·017%, Mn 0·46%, Cr 2·26%, Ni 0·16%, Mo 0·98%, N (by vacuum fusion) 0·008–0·010%.

Bismuth

Bismuth (purity > 99·99%) was supplied by Mining and Chemical Products Ltd. Impurities were traces of lead, tin, iron, oxygen, and chlorine. It was filtered *in vacuo* through a 30μ glass filter to remove the bulk of the dross in the original material.

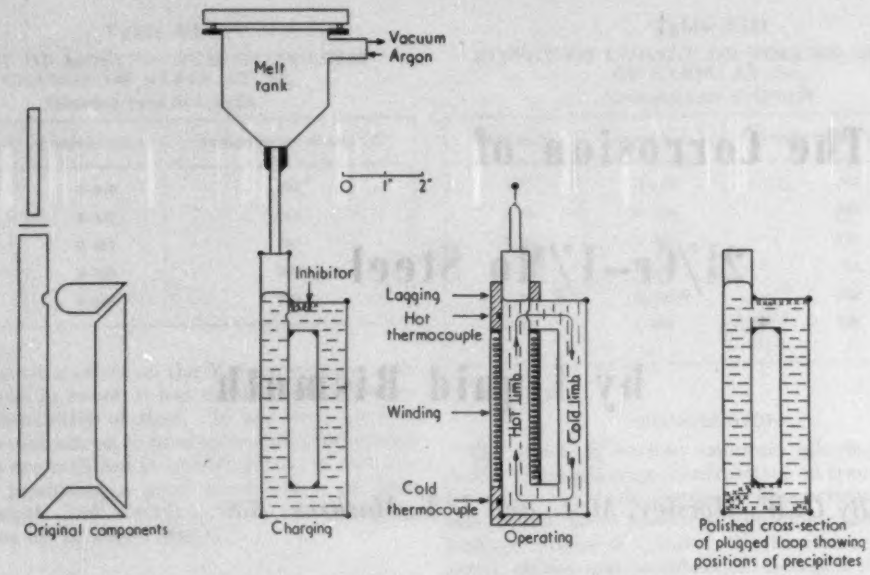


Fig. 1—Diagrammatic history of a loop experiment

Zirconium

Zirconium (purity $> 99{\cdot}0\%$) was supplied by Murex Ltd. The main impurities were hafnium, iron, nitrogen, oxygen, and carbon.

Calcium

Calcium (purity $> 99{\cdot}0\%$) was supplied by I.C.I. The main impurities were magnesium, sodium, potassium, and chlorine.

LOOP CONSTRUCTION, OPERATION, AND EXAMINATION

The designs of the thermal convection loops were governed by the size of the irradiation holes in BEPO (4 in. dia.), the temperature differential between the hot and cold limbs of the loop (100–150° C), and such experimental requirements as facilities for sampling and making additions to the liquid metal circulating in the loop. By trial and error the loop shown in Fig. 1 was developed for in-pile and laboratory corrosion tests. To give the required temperature differential the circulating bismuth was impeded by a ¼-in. dia. hole from the hot limb into the top horizontal arm of the loop.

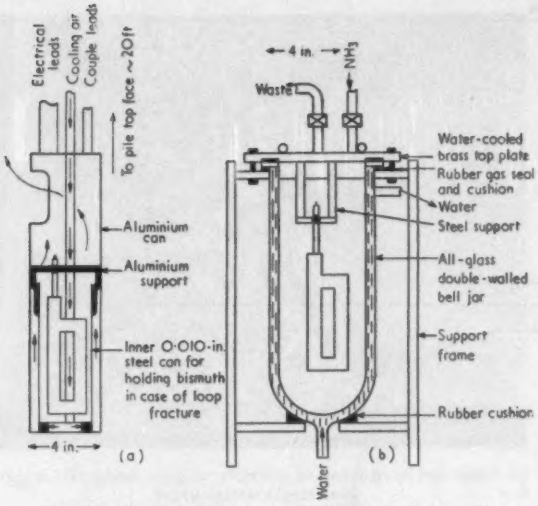
The parts made from the steel tubing were cut and shaped, the internal surfaces degreased with acetone, and the four sections argon-arc welded together.* The welds were pressure tested at 30 lb/in² and the loops descaled in hydrogen at 600° C for 3–4 h. After tapping out any loose particles of reduced scale, a mild-steel cap and filling tube were welded to the open end of the loop. This operation visibly oxidized only a small area of the steel at the top of the hot limb which took no direct part in the corrosion test.

After inserting in the loop the desired quantities of calcium† (up to 500 p.p.m.) and zirconium (up to 500 p.p.m.) as granules and turnings respectively, the filling tube was brazed to an evacuable melt-tank, an amount of filtered bismuth sufficient to fill the loop to the top of its upper horizontal arm was placed in the tank and the tank and loop evacuated to $\sim 10\mu$ Hg. The bismuth was then melted and forced by argon at 1 atm into the loop, the additives rising to the top horizontal arm of the loop and being prevented from getting to the free surface of the bismuth by the upper edge of the orifice. The bismuth was then allowed to freeze from the bottom upwards and the metal expanded in the free space at the top of the hot limb. After checking the level of the metal and the position of the additives by gamma-radiography, the feed tube was heated, crimped, and sawn, and the loop finally sealed by brazing across the crimped end. The hot limb was wound with 22-s.w.g. Nichrome wire insulated from the steel by steatite beads and lagged with a second layer of beaded wire. To the hot limb were spot-welded two 20-s.w.g. chromel–alumel thermocouples at the positions opposite the centre lines of the horizontal arms of the loop. The top one was attached to a Kelvin-Hughes Mark III temperature controller and the lower one to either a Kent recorder or an ether pyrometer. Both thermocouples were lagged with layers of asbestos string. The bismuth was melted (m.p. 271° C) and circulated by heating with the hot limb winding, the metal in the cold limb being melted by conduction through the loop.

These small loops were operated under slightly different thermal conditions, the initial temperature gradient between the hot and cold limbs being adjusted by altering the amount of lagging on the cold

* The welds received no stress relief other than that given by the hydrogen treatment and incidental to the corrosion test.

† To avoid loss of inhibitor by reaction with non-metallic impurities such as oxygen and chlorine in the bismuth, calcium was added to getter these substances.



(a) For in-pile radiation test (b) For running in ammonia

Fig. 2—Method of mounting loop

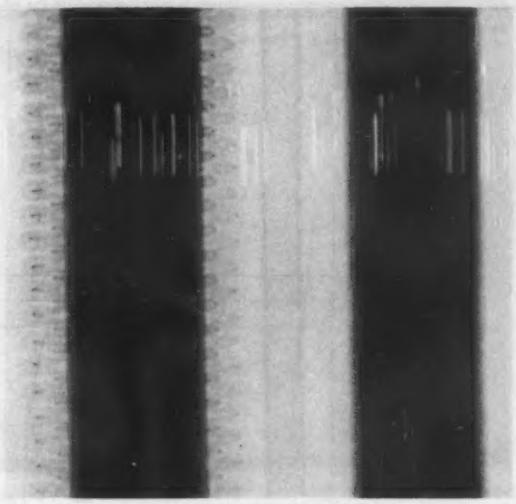


Fig. 4—Section of a gamma-graph of Loop VI × 1

limb. The arrangement of one of these loops in-pile is shown in Fig. 2*a*. The method adopted for running them in inert, reducing, or nitriding atmospheres is shown in Fig. 2*b*.

To study the change in composition in the bismuth in a loop as the test progressed, the design shown in Fig. 3 was used. Although more complex, it was commissioned and instrumented in a manner similar to the small rectangular loops. Sampling and additions to the bismuth were made through a vacuum valve supplied by the Hawker-Siddeley Nuclear Power Co., the sampler or additive being fixed to a silver steel rod which passed through the valve and out to the atmosphere through a Wilson seal. Sampling involved evacuating the space in the loop above the bismuth, plunging the sampler into the metal, and forcing it by argon pressure through the 12% Cr, 88% Fe 30μ filter (*see* Fig. 3) into the evacuated space above it. On withdrawing the sampler through the valve, surface tension was sufficient to hold the molten bismuth above the filter. After the specimen had solidified the sampler was sawn open and the bismuth drilled out. Samples of metal weighing between 5 and 10 g were obtained in this way.

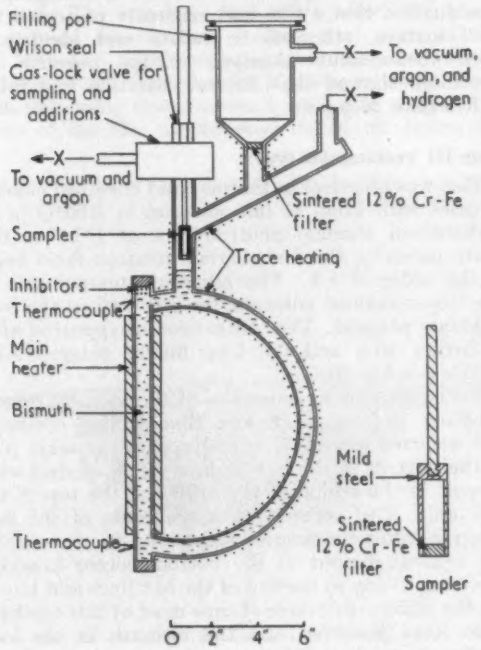


Fig. 3—Semi-circular loop for studying the variation with time in the composition of inhibited bismuth

While in operation, particularly in more recent experiments, the corrosion proceeding inside a loop was observed by gamma-graphs. Satisfactory results, an example of which is shown in Fig. 4, were obtained by using Ilford B film and a 0·1–1·0-c Ir 192 source. Exposures of between 1 and 20 h were used depending on the strength of the source and the geometry of the system.

On shut-down the loops were sectioned longitudinally, one half being metallographically polished to examine the corrosion effects. From the other were obtained specimens of bismuth and corrosion deposits for chemical analysis and specimens of steel for metallographic examination, chemical analysis, and surface-film identification by electron and X-ray diffraction techniques. For examination of the steel surface, specimens were cleaned by dissolving adhering bismuth in boiling mercury (b.p. 357° C). Any mercury sticking to the steel after this treatment was removed by an air blast and, if necessary, by evaporation *in vacuo* (~ 10μ Hg). Precipitates of metallic crystals were extracted for analysis by dissolving the surrounding bismuth in concentrated nitric acid. This treatment did not affect the crystals as they were quickly passivated by the acid.

LOOP TESTS AND RESULTS

The results of the experiments are given in chronological order. Only the results of those experiments

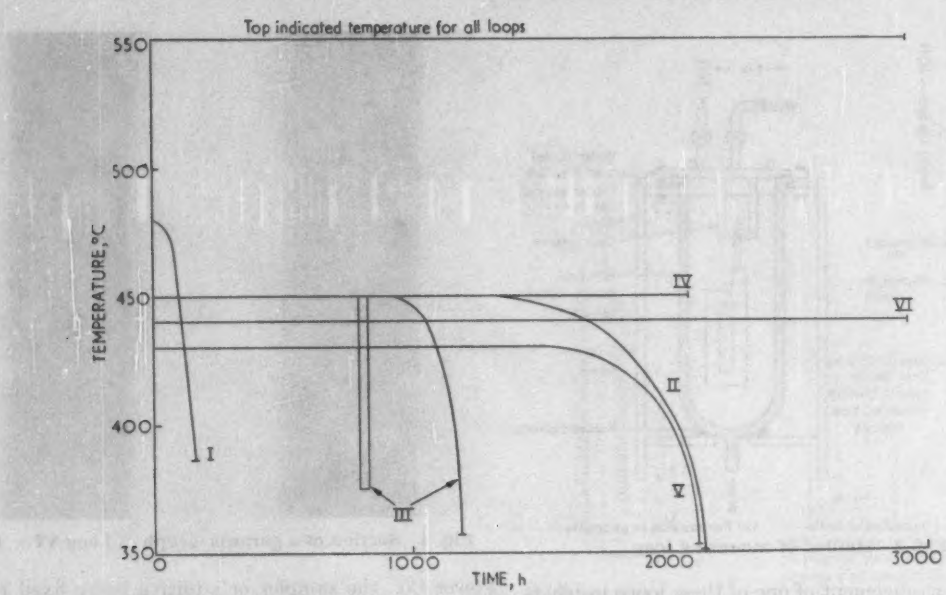


Fig. 5—Variation of indicated minimum temperatures of Loops I–VI with time

that gave valuable information on the corrosion and inhibition mechanism are presented.

Loop I (rectangular type)

This experiment was to determine the resistance of the steel to dynamic corrosion by pure liquid bismuth as a control for assessing the efficiency of the corrosion inhibitor. The initial temperatures recorded by the thermocouples at the top and bottom of the hot leg were 550° C and 480° C respectively. Soon after beginning the run, the temperatures began to diverge (*see* Fig. 5), a minimum at the lower thermocouple being reached after 160 h. This behaviour associated with the impedance of the flow of liquid round the circuit by steel transferred from the hot limb to the colder regions of the loop is characteristic of a loop test in which extensive mass-transfer is taking place. The principal plug of small crystals of steel collected at the coldest part of the circuit at the corner of the loop at the bottom of the hot limb. An example of this type of plug is shown in Fig. 6.

On sectioning the loop it was found that although the steel had been intergranularly attacked the entire length of the hot limb, there was no sign of any pitting corrosion. The thickness of steel dissolved increased with increasing temperature to a maximum of 0·012 in. corresponding to a corrosion rate of 0·65 in./year. Analysis of the bismuth in the hot limb for the principal constituents of the steel gave (in p.p.m.) Fe 280, Cr 35, Mo 120. Analysis of the plug crystals showed that their composition was Fe 86%, Cr 14%, Mo 0·2%, Ni 0·5%.

Loop II (rectangular type)

This loop was run with initial indicated maximum and minimum temperatures of 550° and 450° C to test the effect of the zirconium inhibitor on the corrosion rate of the steel and to act as a control for an identical in-pile loop (Loop III). The bismuth contained 500 p.p.m. Ca and 250 p.p.m. Zr. The lower temperature remained steady for 1500 h and then began to fall, plugging finally occurring after 2146 h (*see* Fig. 5). Examination of the loop revealed that the hot limb was very badly pitted and that the steel had been attacked intergranularly at the base of the pits (*see* Fig. 7). Furthermore the weld metal fared no better or worse than the parent metal. Although it was apparent from the metallographic examination that a film had originally protected the steel surface, attempts to isolate and identify it were unsuccessful. Analysis of the bismuth for zirconium showed that its concentration had fallen to less than 20 p.p.m.

Loop III (rectangular type)

This was identical in thermal and chemical characteristics with Loop II but was run in BEPO in an undisturbed thermal neutron flux of $1–1·5 \times 10^{12}$ neutrons/cm²/s, the fast/thermal neutron ratio being of the order of 1/1. The minimum temperature of the loop remained constant for 850 h when the loop suddenly plugged. The obstruction disappeared after a further 40 h and the loop finally plugged after 1200 h (*see* Fig. 5).

Metallographic examination of the loop by remote handling techniques showed that pitting corrosion had occurred and that, in addition to the main plug at the bottom of the hot limb, crystals of steel were present in the region of the orifice at the top of the hot limb. This suggests that the cause of the flow stoppage after running for 850 h was due to some of the original deposit at the bottom corner breaking away and rising to the top of the hot limb and blocking the orifice. In course of time most of this blockage must have dissolved and the bismuth in the loop finally stopped circulating owing to the build-up of the normal type of cold limb plug.

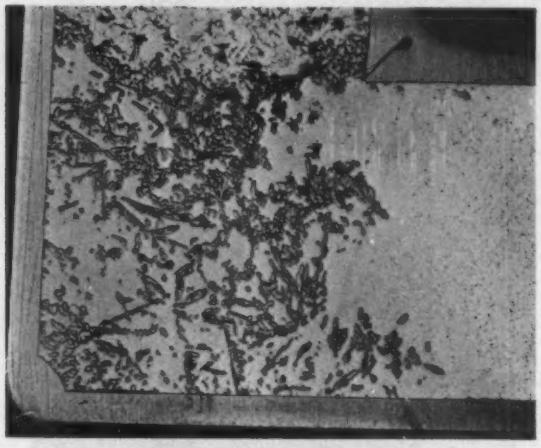


Fig. 6—Typical plug formation at bottom of hot limb in rectangular-type loop × 3

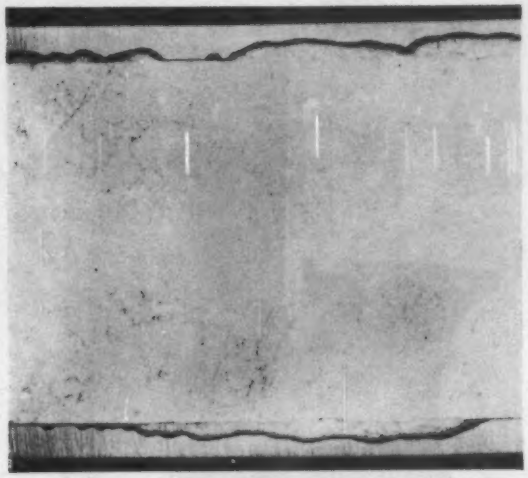


Fig. 8—Example of severe pitting corrosion of steel from hot limb of Loop IV × 3½

Loop IV (rectangular type)

Since the results of Loop II suggested that the protection afforded the steel by 250 p.p.m. Zr in the bismuth was far from satisfactory and since this concentration almost disappeared during the course of the experiment, Loop IV was run under thermal conditions identical with those of Loop II (550–450° C nominal) but with bismuth containing 500 p.p.m. Ca and 500 p.p.m. Zr. Even though no divergence in the temperatures was observed after 2000 h (*see* Fig. 5) a gamma-graph of the loop revealed extensive pitting corrosion in the hot limb (*see* Fig. 8) which was penetrating the steel at the rate of 0·17 in./year. The loop was shut down after 2088 h and subsequent examination showed that parts of the hot limb had been protected from corrosive attack, but above 520° C (*see* Loop VII) there was a tendency with increasing temperature for the film to spall off. Some of the film on the steel flaked off during the vacuum treatment following the mercury-bath removal of the bismuth. X-ray examination of this scale showed that it was tetragonal zirconia, a form which is stable at room temperature when it contains as impurities significant amounts of alkaline earth oxides.[5] Chemical analysis of this material confirmed the presence of about 5% lime.

Analysis of crystals from the deposit at the bottom of the hot limb showed their composition to be 2¼% Cr, 97¾% Fe. Analysis of the bismuth gave (in p.p.m.) Ca 200, Zr < 20, Fe 6, Cr 7, Mo < 1.

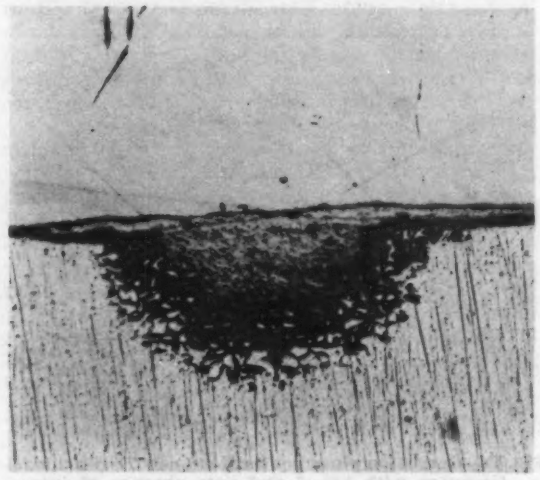


Fig. 7—Example of pitting corrosion by inhibited bismuth in steel from hot limb of Loop II × 90

Loop V (semi-circular type)

Evidence from Loops II and IV indicated that the inhibitor prevented corrosion until the breakdown of a film of some zirconium compound which formed on the surface of the steel during the operation of the loop. Breakdown was accompanied by catastrophic pitting corrosion presumably due to either lack of zirconium or the other substance in the compound. In this loop run with an indicated temperature range of 550–430° C, an attempt was made to find out whether pitting corrosion could be prevented or the film repaired by keeping the zirconium concentration at or near its original value.

To maintain its concentration between 200 and 250 p.p.m., additions of zirconium were made at intervals of about 200 h to the loop in which the bismuth originally contained 500 p.p.m. Ca and 250 p.p.m. Zr. In spite of consuming 950 p.p.m. Zr, the steel suffered from pitting corrosion and the loop plugged after 2130 h (*see* Fig. 5). Calculations indicated that sufficient zirconium had been added to the loop to combine with all the nitrogen in the steel. However, analysis of a sample of steel from the hot limb, which had both its outer and inner layers removed by shot-blasting, showed that its nitrogen content (80–100 p.p.m.) was identical with that of a sample of steel from the cold limb and also with that of a sample of the original material. Moreover, no evidence was obtained for the presence of zirconium in these samples.

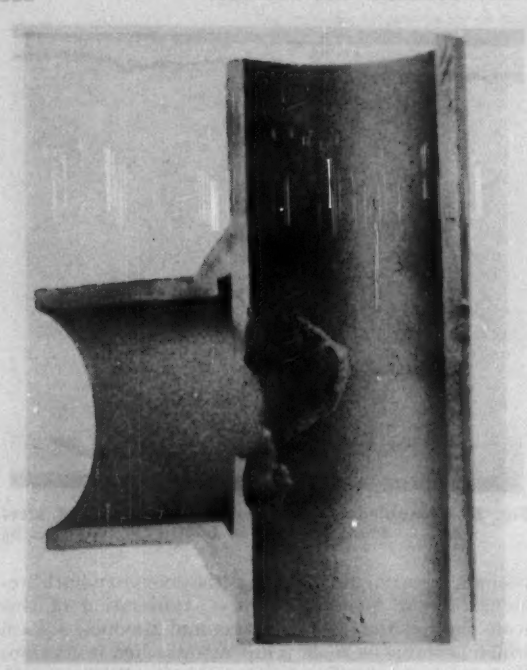


Fig. 9—Corroded orifice area of Loop VI due to local deficiency of nitrogen in the steel × 2

An attempt was made to isolate the broken film that could be seen on polished specimens. The powder obtained from a mercury-cleaned sample of steel from the hot limb was identified by X-rays as mainly iron; no trace of any zirconium compound was detected. Spectrographic examination of the corroded surface of this sample, from which all the loose powder had been previously removed by gentle brushing, identified zirconium. However, microscopical examination and microhardness tests failed to reveal the depth to which the zirconium had diffused into the steel.

Loop VI (rectangular type)

The previous loop experiments had indicated that about 200 p.p.m. Zr was insufficient to guarantee renewal of the protective film and that if the film was not re-formed the zirconium probably diffused into the unprotected steel surface. Furthermore, examination by electron diffraction of the surface film on uncorroded steel specimens from a large pumped liquid-bismuth loop at Harwell had confirmed Gurinsky's view[3] that the principal protective compound is zirconium nitride. Since a film which readily broke away from the steel surface had been identified as tetragonal zirconia (Loop IV) it was considered that the only method of preventing rapid corrosion of the steel was to prevent oxygen reaching the bismuth/steel interface and to increase the nitrogen content of the steel.

After its exterior had been shot-blasted to facilitate nitriding, Loop VI containing bismuth with 500 p.p.m. Ca and 500 p.p.m. Zr was run in dry ammonia (*see* Fig. 2*b*) with maximum and minimum temperatures of 550° and 440° C. Gamma-graphs of the loop were

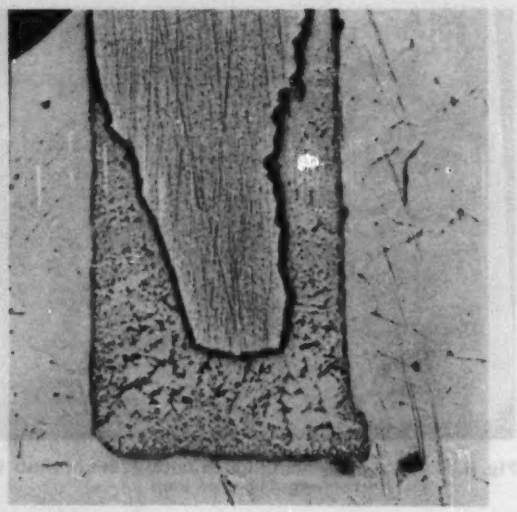


Fig. 10—Corroded lip of orifice of Loop VI. Note original outline of the steel marked by the remaining film shell × 25

taken every week (*see* Fig. 4) and the ammonia atmosphere renewed daily. After about 2800 h, a slight precipitate was detected at the bottom of the hot limb and the orifice of the loop appeared to have been corroded. Furthermore, pockets of gas, presumably hydrogen, were appearing in the horizontal arms of the loop and since it was thought that these would impede the bismuth flow, the loop was shut down after running 2930 h.

Visual examination of the polished half of the loop indicated that the pitting corrosion had been prevented in those regions where it had been previously observed. However, the area around the orifice had been corroded and its extent can be seen from the photograph of the cleaned top portion of the loop in

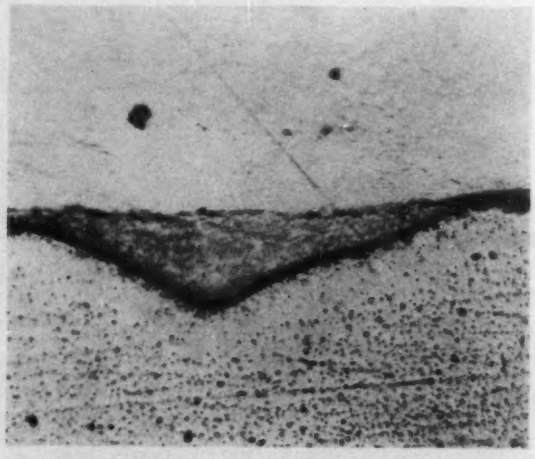


Fig. 11—Corrosion pit in hot limb of Loop VI (nitrided). Compare with Fig. 7 and note absence of intergranular penetration at base of pit and the re-formation of the protective film × 330

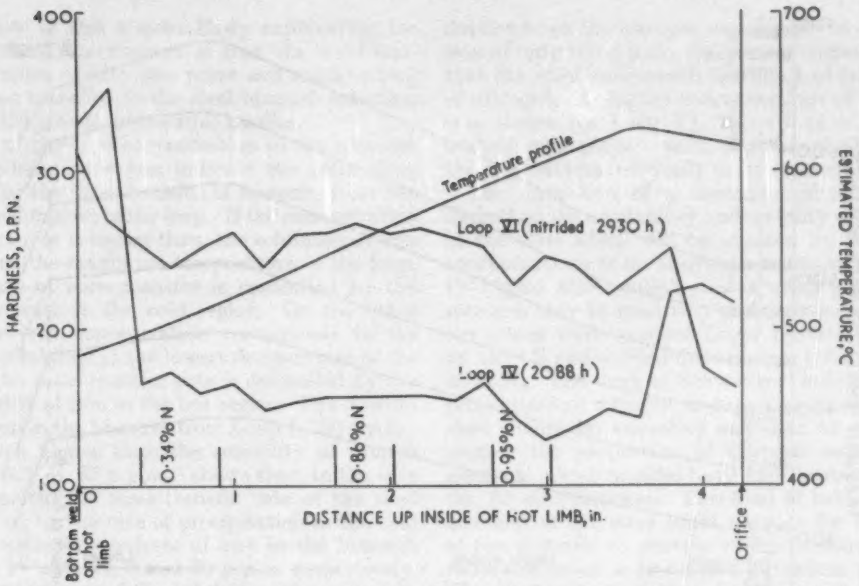


Fig. 12—Variation of hardness of the steel from the hot limbs of Loops IV and VI

Fig. 9. Even at this point the original film existed as a shell (*see* Fig. 10) inside which the bismuth was considerably harder (D.P.N. 19–21) than that in the main stream (D.P.N. 9–10).

Microscopical examination of the hot limb showed that there had been some pitting corrosion (*see* Fig. 11) but that the pits had been sealed off by the growth of a new film. Furthermore, the type of intergranular attack shown in Fig. 7 had been prevented and the maximum corrosion rate deduced from the size of the small pits corresponded to about 0·010 in./year. In marked contrast to the results from the other loops, analysis of the bismuth showed that it still contained 470 p.p.m. Zr. Also present were (in p.p.m.) Ca 150, Fe 10, Cr 10, Mo < 1. Again, unlike the behaviour of the steel from the corroded loops, the liquid bismuth readily de-wetted from the steel tubing when a section of the loop was heated *in vacuo*. Moreover, examination by electron diffraction of the surface of steel specimens from the hot limb showed that it was covered by a film of zirconium nitride.

The steel in the hot limb was heavily nitrided, samples from it that had been at estimated temperatures of 500°, 550°, and 600° C (*see* Loop VII) contained 0·34%, 0·86%, and 0·95% N respectively. Hardness measurements (*see* Fig. 12) showed that the steel averaged about 250 D.P.N. compared with an average value of 150 D.P.N. for a similar sample taken from Loop IV. Metallographic examination of the steel tubing revealed that it had a friable outer case which varied in thickness from 0·003 to 0·005 in. and the original ferrite-pearlite of the steel had been altered to a rapid-etching sorbitic structure.

Loop VII (rectangular type)

The authors were informed by Gurinsky[6] that temperatures measured by couples spot-welded to the walls of a thermal convection loop often differed considerably from those obtained by direct measurement inside the flowing liquid. Since the experiments conducted with Loops I–VI were of a comparative rather than an absolute nature, many of the conclusions that could be drawn from them would not be affected by lack of more accurate temperature measurements. However, for comparison with results from other laboratories the temperature distribution inside the rectangular type loop was studied. This was done by measuring the temperature of the bismuth directly with a chromel–alumel couple sheathed in an ⅛-in. outer dia. steel tube at ½-in. intervals up the entire length of the hot limb (*see* Fig. 13). Estimates of the velocity of the flowing bismuth were also made with this loop by putting in a heat pulse with an oxy–coal-gas flame at the bottom horizontal arm and measuring the time lag between the pick-up of this pulse by the bottom and top thermocouples. Velocities of between 3 and 4 mm/s were recorded.

DISCUSSION

The higher rates of corrosion of the 2¼%Cr–1%Mo steel by pure and inhibited bismuth observed in this investigation compared with those obtained by Weeks *et al.*[2] may be attributed principally to the higher temperature, 625° C as opposed to 550° C, at which the loop experiments were conducted. Other contributory factors may have been the different size and shape of loop employed and the use of bismuth with calcium and zirconium additions as opposed to bismuth containing small concentrations of magnesium, zirconium, and uranium.[2]

From the temperature data from Loop VII and examination of Loops II and IV, the rate of penetration of the steel by inhibited bismuth at 625° C was estimated to be 8 times as fast as that occurring at 550° C. If it is assumed that the plugging time in an inhibited loop is inversely proportional to the penetration rate, then had these loops been run with a true maximum temperature of 550° C they would

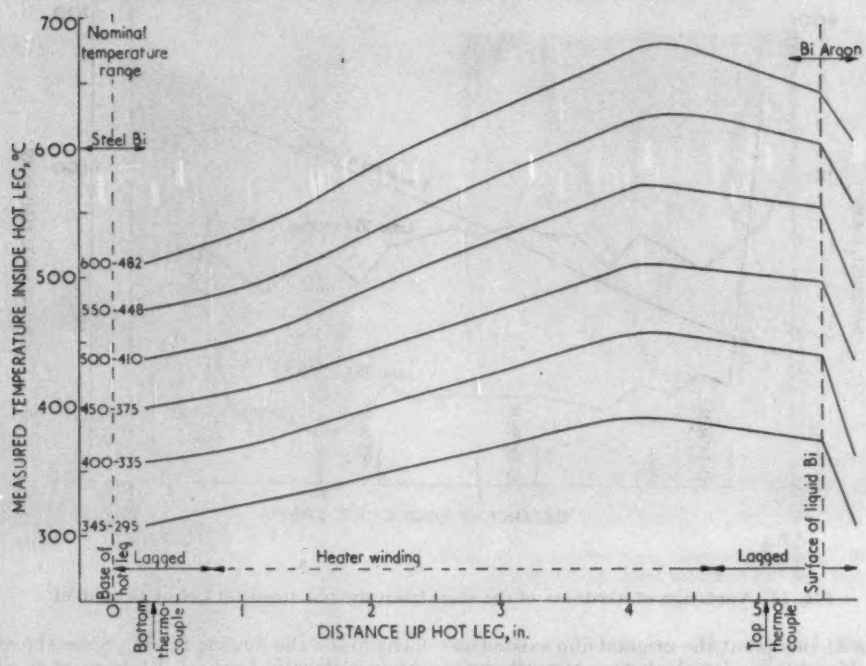


Fig. 13—Temperature distribution in the hot leg of the rectangular-type loop

have had lives of around 16,000 h. Although this order of loop life would have been more in accord with the American data,[2] the estimated corrosion rate, 0·020 in./year, is still excessive for engineering purposes. Loops I, II, and IV confirmed that inhibition by zirconium could reduce the mass-transfer rate of the steel, as indicated by the ratio of the plugging times, by at least a factor of ten. However the effective corrosion rate of the steel was only reduced by a factor of four since the inhibited bismuth caused localized pitting corrosion.

An attempt to stop the pitting corrosion by maintaining the zirconium supply in the bismuth at a level at which it was capable of forming an initial protective film (~ 250 p.p.m.) failed (Loop V), but by raising the nitrogen content of the steel to about 1% (Loop VI) the pits were sealed off. This treatment resulted in the corrosion rate of the steel by bismuth at ~ 625° C being reduced from about 0·65 in./year (Loop I) to 0·010 in./year. This lower value of the corrosion rate may be larger than the true rate because it was not known whether the small pits in the nitrided steel grew before or after there had been a substantial increase in the concentration of nitrogen in the steel directly in contact with the bismuth. If they grew in the early stages of the experiment and are ignored as a basis for calculating the corrosion rate, the actual rate may have been as low as 0·001 in./year.

The corroded orifice area of Loop VI (Figs. 9 and 10) which was much softer (D.P.N. 160) than the steel in direct contact with the ammonia (D.P.N. ~ 250) showed the effect of not having sufficient nitrogen in the steel to enable the re-formation of the protective zirconium nitride film. It also demonstrated that keeping oxygen out of the system to prevent the oxidation of the nitride to zirconia does not ensure permanent protection by the film that initially forms on the steel surface. The extent of this corroded area also showed the slow rate at which the nitrogen diffused through the steel in sufficient concentration to prevent corrosion. Measurements from this part of Loop VI indicated that at 600° C the critical amount of nitrogen had not penetrated more than ¼ in. in ~ 3000 h.

The puzzling feature of Loop IV was the tetragonal zirconia film obtained from its hot limb. It is unlikely that the compound was formed by the oxidation of the nitride during the removal of the bismuth as precisely the same method had been used successfully for isolating very thin films of zirconium nitride. The hydrogen treatment given to the loop before charging undoubtedly removed the oxide scale formed during the fabrication of the loop. Furthermore if an iron oxide scale was on the steel surface at the beginning of the experiment, it would on thermodynamic grounds more likely have reacted with the calcium in the bismuth rather than with the zirconium. The only conclusion is that the oxygen must have come through the steel wall and converted the original zirconium nitride to zirconia. Whether this occurred by diffusion of oxygen through the steel is at present unknown, but, in view of the large size of the oxygen ion (1·3 Å) and of the high binding energies between it and the metal ions in the steel, it would seem to be an unlikely mechanism. It was noticed that the film was very much thicker on that part of the hot limb which had been affected by the welding of the top horizontal arm. Moreover, the weld metal had in places penetrated through the tubing of the hot

limb. In view of this a more likely explanation for the formation of the zirconia is that the weld contained a number of very fine pores and cracks along which oxygen travelled to the steel/bismuth interface and caused the growth of the zirconia film.

Analyses of the iron concentration in the bismuth from convection loops can indicate the controlling mechanism in the mass-transfer of material from the hot to the cold regions of the loop. If the concentration corresponds to, or is higher than, the solubility of iron in bismuth at the maximum temperature of the loop, then the rate of mass-transfer is controlled by the precipitation rate in the cold region. On the other hand if the iron concentration corresponds to the value of its solubility at the lowest temperature of the loop, then the mass-transfer rate is controlled by the rate of solution of iron in the hot region. The concentration of iron in the bismuth from Loop I, 280 p.p.m., a value much higher than the solubility of iron in bismuth at 625° C, 65 p.p.m.,[2] shows that, in the case of pure bismuth, the mass-transfer rate of the steel was controlled by the rate of precipitation in the cold region. In contrast, analyses of iron in the bismuth from Loops IV and VI, 6 and 10 p.p.m. respectively, correspond to values of the solubility of iron in bismuth at temperatures in the range 450–500° C. These values indicate that in the inhibited loops the rate of mass-transfer was controlled by the rate of solution of iron in the hot section. This is all the more remarkable as in both cases there were areas of the loops from which the film had broken away, but, as indicated by Fig. 10, even spalled-off film provided a considerable barrier to the iron getting into solution in the moving bismuth stream.

From the experimental evidence so far obtained, it is only possible to give a rough estimate of the thickness of a protective nitride film. Assuming an even deposition of film, a thickness of 0·2μ was calculated from the loss of zirconium in Loop VI (30 p.p.m.) and the surface area of the steel. This may well have been an overestimate as the results from the other loops suggest that there is a continuous loss of zirconium from the bismuth once the film has broken down. Thus a significant part of this 30 p.p.m. loss was probably taken up by the corroded area around the orifice of Loop VI. Calculations indicated that the thickness of the original protective films in the corroded inhibited loops, assuming they were principally nitride films, could never have been much thicker than 1μ. Such a film would have required all the nitrogen in the steel tube (~ 100 p.p.m.). Since no nitrogen loss was detected from corroded steel specimens the film must have been extremely thin and may have included only those nitrogen atoms left behind from an initially dissolved layer of the steel. This may have been possible as there are enough nitrogen atoms in a 0·001-in. layer of the steel to produce a film of zirconium nitride ~ 200 Å thick. This thickness is quite sufficient for identification by electron diffraction since the electrons only penetrate the film to a depth of between 20 and 40 Å.[7]

It is impossible to say from present experimental evidence whether diffusion of nitrogen through the steel helped towards the build-up of the initial nitride layer. Although analytical evidence suggests that it did not when the nitrogen was present at a concentration of only 100 p.p.m., the pitting corrosion suggests that the steel underneath the film had been denuded of nitrogen. At higher concentrations of nitrogen, as was shown by Loop VI, the diffusion of nitrogen undoubtedly plays a part, if not in the formation of the original film, certainly in its regeneration.

The formation of a zirconium nitride layer will depend on the availability and mobility of the nitrogen in the steel which will be affected by the type and concentrations of its alloying constituents. In a 2¼% Cr–1%Mo silicon-killed steel a small portion of the nitrogen may be relatively mobile in solid solution in the α-iron while another larger portion may be tied up as CrN and a third quantity very firmly anchored as Si_3N_4. The work of Schweitzer[8] indicates that the proportions of nitrogen tied up in various ways in the steel change on annealing and that, as might be expected, the proportion of nitrogen associated with elements whose nitrides have high heats of formation (Si, Al, etc.) increases. This kind of behaviour by the nitrogen in the steel could account for the inability of the material to provide sufficient nitrogen for the re-formation of a protective zirconium nitride film. Thus it is suggested that, in the period between the formation of the initial film and its breakdown, the remaining nitrogen in the steel is ' locked ' by residual free silicon atoms and that the zirconium is unable to break up silicon nitride at the operating temperatures of the loops.

It was proposed earlier in this discussion that the original film was created from the residual nitrogen from a thin layer of steel dissolved away by the bismuth. Besides nitrogen, there would very likely have been phosphorus, sulphur, carbon, and non-metallic inclusions left behind to combine or interact with either the calcium or zirconium. The reaction products would distort and cause imperfections in the nitride film, reduce the ability of the film to key to the steel surface, and generally impair its protective properties. It is suggested that as the nitrogen concentration in the steel is increased the proportion of distorting impurities in the film is decreased and the superior protection provided by the nitride film formed on a heavily nitrided steel can be explained on this basis.

Comparison of the plugging time of the in-pile loop (Loop III, 1200 h) with that of its control (Loop II, 2146 h) suggests that pile radiation may accelerate the corrosion of steel by inhibited bismuth. However one result is not enough to determine its effect unequivocally. Although further work on the effect of radiation was not carried out because it had become clear that the most important task was to find a method of stopping the pitting corrosion, there is no question of its having improved either the corrosion resistance of the steel or the efficiency of the inhibitor.

CONCLUSIONS

The corrosion of a 2¼%Cr–1%Mo silicon-killed steel by liquid bismuth has been studied by means of thermal convection loops constructed from ¾-in. outer dia. 16 s.w.g., tubing working principally over the temperature range 625–475° C with fluid velo-

cities of 3–4 mm/s. The corrosion rate of the steel under these conditions by pure liquid bismuth is at least 0·65 in./year and is only cut to about 0·17 in./year by inhibiting the bismuth with an initial concentration of 500 p.p.m. Zr.

The zirconium in solution in the bismuth slows down the corrosion of the steel by forming a layer of zirconium compounds on its surface, principally the nitride, which prevents it dissolving in the bismuth. This layer gives only a temporary protection, is liable to spall off, and does not re-form. This results in localized corrosive attack of the underlying steel.

By substantially increasing the nitrogen content of the steel (0·01% to ~1%) the corrosion rate is reduced to 0·01 in./year and the experimental results indicate that it may be possible to reduce it to < 0·001 in./year. The increased corrosion resistance of the nitrided steel is thought to be due to its ability to produce a more protective zirconium nitride film containing far fewer distorting impurities than the film that forms on the untreated steel. Moreover, it seems to have sufficient nitrogen available for the repair of the film in the event of its being disrupted.

No detailed conclusions can be drawn concerning the influence of pile radiation on the corrosion resistance of the steel or the behaviour of the zirconium inhibitor. All that can be said is that it has no beneficial effect and may accelerate the corrosion of the steel by inhibited bismuth.

Acknowledgments

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Some Effects of Mechanical Working on the Deformation of Non-metallic Inclusions

By F. B. Pickering, A.Met., A.I.M.

SYNOPSIS

An examination has been carried out into the deformation of various types of non-metallic inclusion during hot working. Various effects have been observed and particular attention has been paid to the effect of the temperature and the extent of hot working upon the deformation characteristics. It has been shown that at high temperatures siliceous inclusions deform and elongate prior to fracturing, but at lower temperatures they fracture with little or no deformation. It has been concluded that fracture of the inclusions is necessary to disperse the larger detrimental inclusions into smaller, less harmful particles, and it is suggested that, to obtain an optimum degree of dispersion, multiple hot-working treatments with intermediate reheatings might be used. 1509

THE TYPE AND DISPERSION of non-metallic inclusions in wrought steel products is known to have a detrimental effect on the mechanical properties. Of these, the fatigue properties[1, 2] and the transverse ductility and impact behaviour are often the most sensitive to these detrimental effects.

During an examination of various Fe–O_2 alloys deoxidized by Si, Mn, or Al, effects were observed in the hot-rolled condition which led to the conclusion that the controlling factors in the dispersion of the inclusions throughout the steel were the temperature and the degree of hot working. It was decided therefore to investigate these effects on the deformation characteristics and the dispersion of inclusions occurring in Fe–O_2–Si alloys. This particular system was chosen because there were indications that a wide variation of plasticity could be obtained in the inclusions, siliceous inclusions were known to be detrimental to mechanical properties, and also because it had been possible to predict the types of inclusions present in alloys of known Si and O_2 contents on the basis of previous work.[3, 4]

The present paper deals with the results of this investigation.

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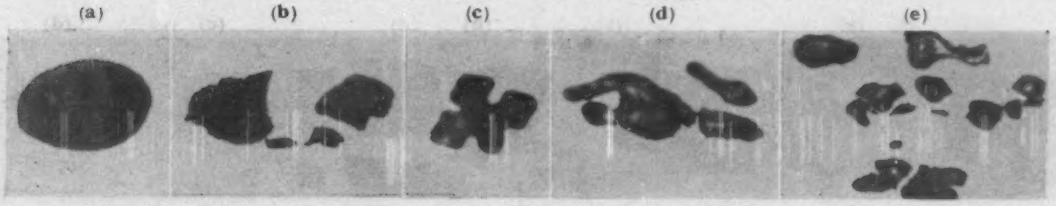


(*a*) Cast RM.39. Deformed FeO inclusion × 1500
(*b*) Cast RM.40. Deformed and fractured (Fe Mn)O inclusion × 2500
(*c*) Cast RM.134. Dendritic MnO-rich inclusion before rolling × 1000
(*d*) Cast RM.134. Deformed dendritic MnO-rich inclusion × 1000
(*e*) Cast RM.134. Deformation and cracking in segregate of MnO-rich inclusions × 750

Fig. 1—Some typical effects in (FeMn)O inclusions

EFFECTS OBSERVED DURING THE HOT WORKING OF VARIOUS INCLUSIONS

The work was carried out on nine casts, details of which are given in Table I. The ingots were made from sponge iron by high-frequency melting in air followed by deoxidation with the appropriate alloy addition. The casts, 25 lb in weight, were rolled down from approx. 2½-in. square to ¾-in. dia. bar with no special control over the rolling temperature.

Some typical examples of the various phenomena observed were:

(i) Inclusions rich in FeO, which occurred in the remelted sponge iron, were slightly deformed into ellipsoids (Fig. 1*a*), but when they contained MnO in solid solution, fracture often occurred (Fig. 1*b*). On the other hand, inclusions rich in MnO showed considerable plasticity (Figs. 1*c* and *d*) although when fracture did occur the inclusions appeared rather brittle (Fig. 1*e*). The effect may, however, have been due to lack of control over the finishing temperature.

(ii) Duplex FeO–silicate inclusions often fractured (Fig. 2*a*) and this occurred mainly along the interface between the two phases. A brittle type of fracture also often occurred in the silicate (Fig. 2*b*), after considerable deformation. Typical flat-ended silicates resulting from transverse fracture are shown in Fig. 2*c* whilst a chipped silicate is illustrated in Fig. 2*d*.

(iii) Some silicate inclusions showed apparently different degrees of plasticity at the surface of the inclusion compared with the centre. This resulted in fracture being followed by some deformation (Fig. 3*a*), probably due to friction effects at the metal/inclusion interface. Such effects also probably result in the tilting of the fractured blocks of inclusion in Fig. 3*a* to allow easier flow of metal past them. A further effect of flow of the inclusion due to friction at the interface with the metal is the fishtailing shown in Fig. 3*b* and more clearly illustrated later. Occasionally, glassy silicates showed evidence of being compressed (Fig. 3*c*) presumably owing to vertical forces between the rolls.

(iv) In duplex inclusions such as those containing FeO and hercynite ($FeO.Al_2O_3$), in which one phase is very much harder than the other, the harder hercynite appears undeformed, whilst the more plastic FeO deforms appreciably (Fig. 3*d*).

The above observations illustrate some of the effects produced by hot deformation on various types of inclusion. It was evident that the dispersion of inclusions throughout a wrought product would probably be dependent on the manner in which deformation and fracture occurred. Repeated deformation and fracture could lead to a fine dissemination of inclusions, such as silicates, and this might be the mechanism by which improved transverse properties have been claimed for multiple forging treatments.

To obtain data on the effect of the temperature and degree of deformation on various types of inclusion, an investigation was undertaken into the effects of these variables upon the inclusions occurring in Fe–O_2–Si alloys.

Table I

MATERIALS USED IN INITIAL EXPERIMENTS

Cast No.	Steelmaking Details
RM.39	Re-melted sponge iron, approx. 1% O_2
RM.40	Sponge iron, deoxidized with 0·75% Mn
RM.134	" " " " 1·2% Mn
RM.41	" " " " 0·5% Si
RM.135	" " " " 0·5% Si
RM.42	" " " " 0·5% Mn and 0·3% Si
RM.136	" " " " 0·5% Mn and 0·3% Si
RM.43	" " " " 0·3% Al
RM.137	" " " " 0·8% Al

PLASTICITY OF NON-METALLIC INCLUSIONS OCCURRING IN THE SYSTEM Fe–O_2–Si

Large silicate inclusions are known to be detrimental in steel, and this was one of the reasons for the choice of the Fe–O_2–Si system, together with the belief that a variation in plasticity could also be obtained. The composition of the ingots was derived from the work of Evans and Sloman,[3] three 112-lb casts being made by air-melting in a high-frequency furnace. Details of these casts were:

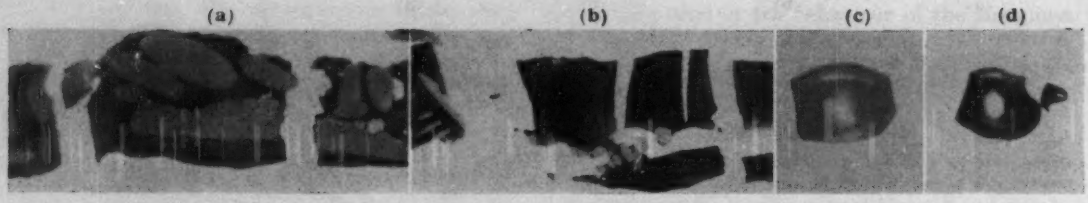
Cast RL.106: Remelted sponge iron containing about 1% O_2

Cast RL.104: Remelted sponge iron deoxidized by Si in the ratio $\frac{Si}{O_2} = 0{\cdot}2$

Cast RL.105: Remelted sponge iron deoxidized by Si in the ratio $\frac{Si}{O_2} = 1{\cdot}0$

It was expected, on the basis of previous experience[3] that these proportions of $Si : O_2$ would produce FeO in Cast RL.106, FeO + silicates in Cast RL.104, and glassy silicates in Cast RL. 105.

Each cast was poured into four 25-lb ingots and one ingot from each cast was rolled into ¾-in. dia.



(*a*) Cast RM.42. Fracture along FeO silicate interface × 1500
(*b*) Cast RM.42. Severe cracking of silicate × 1500
(*c*) Cast RM.135. Straight ends of fractured silicate × 750
(*d*) Cast RM.135. Chipped and fractured silicate × 750

Fig. 2—Some effects of cracking in silicate inclusions

bar and 1-in. square billet within the following temperature ranges:

(i) above 1100–1150° C
(ii) between 1000° and 1050° C
(iii) between 900° and 950° C
(iv) below 800° C

Care was taken that all the hot working was carried out within the required temperature range, by frequent checking of the temperature during rolling. When the lower temperature limit was reached in any particular range, the stock was reheated and, after removal from the reheating furnace, no working was started until the temperature had fallen to the required range. When the section size had been reduced to 1-in. square billet, part of the material was cut off and the remainder rolled to ¾-in. dia. bar, still observing the above practice.

Apart from one or two instances when the ingot broke up during rolling, material was available at two reductions in each temperature range. The material available for the investigation is shown in Table II.

INCLUSIONS IN THE AS-CAST ALLOYS

Cast RL.106 Fe–O_2 Alloy

Most of the inclusions were small spheroidal FeO (Fig. 4*a*), although the first two ingots poured contained some larger slag particles (Figs. 4*b* and *c*), showing various amounts and dispersions of FeO in silicate. The matrix of these slag inclusions was often an FeO–silicate eutectic. Very occasionally, large three-phase slag masses were seen (Fig. 4*d*) in which the third phase was idiomorphic.

Cast RL.104 Si: O_2 = 0·2

The inclusions were duplex spherical particles, often quite large, but there was also a fine dispersion of mainly FeO spheroids (Fig. 5*a*) in the steel. The duplex inclusions consisted of varying proportions of FeO and silicate, with occasionally crystalline fayalite ($2FeO.SiO_2$), as seen in Figs. 5*b–d*. Sometimes dendrites of FeO were seen in either a crystalline or glassy matrix (Figs. 5*e* and *f*).

Cast RL.105 Si: O_2 = 1·0

In all four ingots from this cast, the inclusions were small glassy silicates (Figs. 6*a* and *b*).

In general, therefore, the inclusions observed were those which had been expected from the compositions chosen. The large slag masses in the first two ingots poured in Cast RL.106, whilst not being expected, did allow some interesting observations to be made, as will be described later.

METHOD OF ASSESSING PLASTICITY

It can be shown that when a spherical inclusion is deformed by hot deformation into an ellipsoid within the mass of the steel, the ratio length:width of the inclusion is constant for any section parallel to the major axis of the ellipsoid, i.e. the longitudinal direction. By measuring the ratio of major to minor axes for such longitudinally sectioned inclusions, a ratio can be obtained which is then compared with a similar ratio for the steel as a whole.

With this in view, average values of the length: width ratio of various types of inclusion were measured after being subjected to differing deformation variables.

To compare with the plasticity of the mass of steel itself, which is the standard against which the plasticity of the inclusion is measured, it can be shown that if a reduction in cross-sectional area of the original ingot is effected from x_1 to x_2 then the length: width ratio is given as a/b, where

$$\frac{a}{b} = \frac{x_1^{\frac{3}{2}}}{x_2^{\frac{3}{2}}}$$

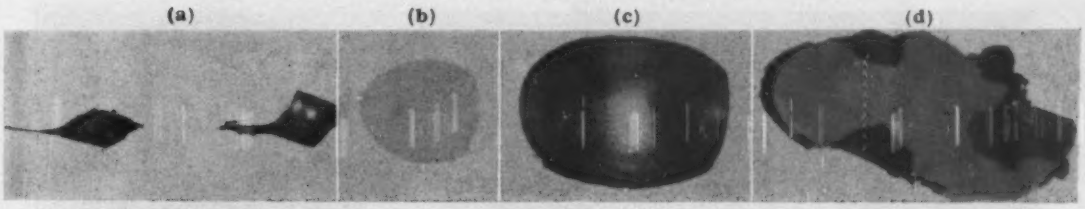
From the known reductions in cross-sectional area, this ratio was calculated for each bar or billet. A comparison was then made between the length:width ratio for the inclusion and that for the steel, the former ratio being divided by the latter to give a measure of the plasticity of the inclusion compared with the steel.

Values greater than unity mean that the inclusion deforms more than the steel, whilst zero plasticity of the inclusion is measured as the reciprocal of the length:width ratio of the steel. It also follows that the further the index departs from unity, the greater will be the relative movement at the inclusion/metal interface during deformation.

Table II
AVAILABILITY OF MATERIAL

Rolling Temperature, °C	RL.106 Bar	RL.106 Billet	RL.104 Bar	RL.104 Billet	RL.105 Bar	RL.105 Billet
Above 1100–1150° C	Available	Available	Available	Available	Not available	Not available
1000–1050° C	,,	,,	,,	,,	,,	,,
900–950° C	Not available	Not available	,,	,,	Available	Available
Below 800° C	Available	Available	,,	,,	,,	,,

Bar material was ¾ in. dia. Billet material was 1 in. square



(*a*) Cast RM.136. Broken, tilted, and deformed silicate × 750
(*b*) Cast RM.135. Friction effects at silicate/metal interface × 750
(*c*) Cast RM.135. Compressed silicate inclusion × 750
(*d*) Cast RM.43. Undeformed hercynite within deformed FeO × 750

Fig. 3—Some further effects of deformation

EFFECT OF TEMPERATURE AND REDUCTION OF CROSS-SECTION DURING ROLLING ON DEFORMATION OF THE INCLUSIONS

The average initial cross-section of the ingots was 6·25 in² and those of the ¾-in. dia. bar and 1-in. square billet were approx. 0·45 and 1 in² respectively. A value for the *a*/*b* ratio for the steel was calculated for each particular specimen, there being small variations in the dimensions of the rolled products. These values were then used to calculate the plasticity of the particular inclusions.

Cast RL.106 Fe–O_2 Alloy

Rolling temperature above 1100–1150° C—In the ¾-in. bar material the smaller FeO inclusions did not deform (Fig. 7*a*), probably because the area of contact between the metal and the inclusion was insufficient to furnish large enough forces to deform the inclusion. On the other hand, the large FeO particles deformed appreciably (Fig. 7*b*), and some fractured (Fig. 7*c*). The slag masses showed considerably more overall plasticity than the FeO as the accompanying figures indicate, although they often broke up (Fig. 7*d*), the harder phases breaking away from the main inclusion mass.

At the smaller reduction, the 1-in. square billet, the small FeO particles again did not deform, but the slag inclusions showed an increased plasticity with fracture often occurring at the oxide/silicate interface (Fig. 7*e*). The generally increased plasticity of the slag over the oxides is no doubt due to the silicate as the oxide in the slag is but little deformed (Fig. 7*f*).

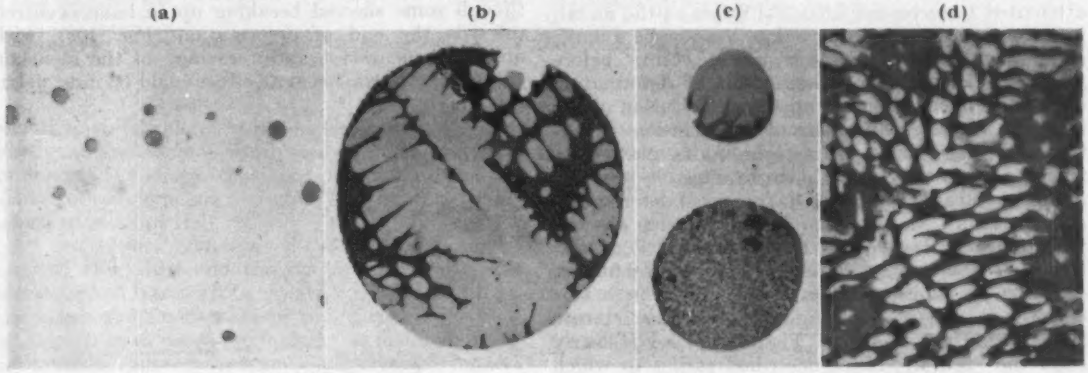
The results of the measurements of the plasticity of the various inclusion products are given in Table III.

Rolling temperature 1000–1050° C—The small FeO inclusions in the round bar were not deformed, but the larger FeO particles were. Deformation and fracture of the slag masses was very similar to that occurring at higher rolling temperatures. At the smaller reductions in the square billet, the effects were generally similar to those in the bar material. Values for the plasticity of the various phases are given in Table III.

Rolling temperature below 800° C—At both reductions, the small FeO inclusions were slightly deformed, although to a less extent in the billet than in the bar (Figs. 7*g* and *h*). There were no large oxides or slag in this ingot to compare with the effects of the higher rolling temperatures, the plasticities of the small FeO particles being shown in Table III.

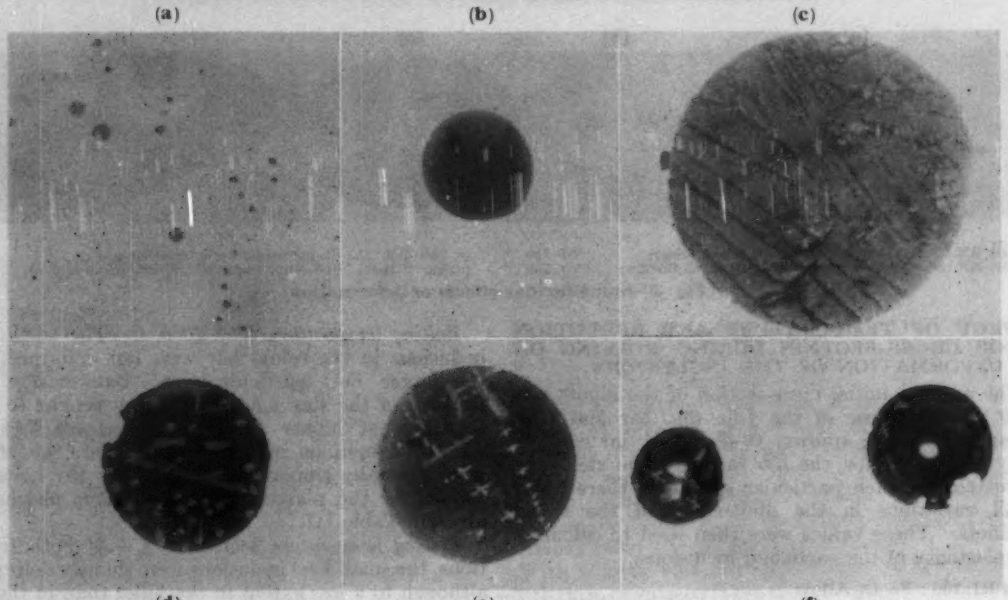
Cast RL.104 Si: $O_2 = 0·2$

Rolling temperature above 1100–1150° C—In the bar material, the silicates had been both heavily deformed and fractured (Fig. 8*a*), and the absence of clean fracture facets indicates that further deformation had occurred after fracture. Considerable variation in plasticity prior to fracture was observed (Figs. 8*b* and *c*) and it seems that the size of the particles, in affecting the forces at the metal/inclusion interface, can alter the deformation prior to fracture, the larger particles fracturing earlier. Differences in composition and the degree of crystallinity of the silicate inclusions can also greatly affect these phenomena. Some of the broken and deformed silicates showed a marked tilting of the fractured blocks (Figs. 8*d* and 3*a*). In the duplex inclusions, the sili-



(*a*) Single-phase FeO inclusions × 750
(*b*) Slag containing FeO in eutectic matrix × 750
(*c*) Varying amounts and dispersions of FeO in silicate × 750
(*d*) Details of 3-phase structure in large slag particles × 750

Fig. 4—Cast RL.106. Inclusions in as-cast material



(*a*) Small FeO inclusions × 750
(*b*) Fayalite × 750
(*c*) FeO–fayalite eutectic × 750
(*d*) FeO in fayalite matrix × 750
(*e*) FeO dendrites in fayalite matrix × 750
(*f*) FeO dendrites in glassy silicate matrix × 750

Fig. 5—Cast RL.104. Inclusions in as-cast material

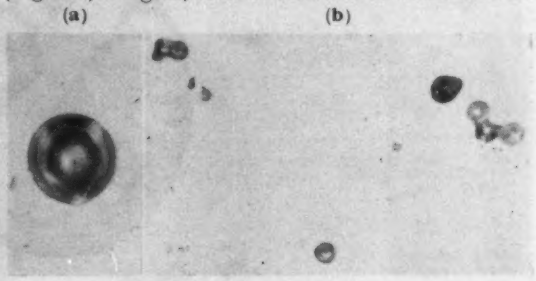
cate was deformed more than the less plastic FeO, which, as observed previously (Fig. 7*d*), often was torn away from the main mass of the inclusion.

In the square billet, the applied reduction had been less and fewer inclusions had fractured, typically deformed and elongated inclusions being shown in Fig. 8*e*, whilst fracture which had occurred towards the end of the deformation is shown in Fig. 8*f*. Compared with the heavy deformation of the silicate, in the duplex inclusions, the FeO had hardly been deformed. Plasticity measurements are given in Table III.

Rolling temperature 1000–1050° C—Very heavy deformation of the silicates had taken place in the bar material, together with fracture at various stages during the deformation process (Fig. 9*a*). The extra deformation at this lower temperature is attributed to increased frictional forces at the metal/inclusion interface, but there does seem to be a limiting amount of deformation which occurs before fracture takes place. This amount of deformation seems dependent not only on the constitution of the inclusion but also on the size of the inclusion. Further deformation also seems to be taking place after fracture has occurred, as shown by Figs. 9*b–g*, which indicate a rather heterogeneous process of deformation and fracture. An unbroken silicate showing obvious variations in plasticity is shown in Fig. 9*b*, whilst fracture early during deformation, followed by further considerable deformation, is shown in Fig. 9*c*. This effect is less marked in Fig. 9*d* indicating fracture later during deformation. Figures 9*e* and *f* clearly show the 'fishtail' effect described earlier in which only deformation near to the metal/inclusion interface appears to have occurred after fracture, whilst Fig. 9*g* shows an inclusion which has fractured just before the end of the deformation process, the cracks in some cases not having opened sufficiently to allow the metal to fill them. This type of effect might be expected to be very detrimental to mechanical properties. In the duplex inclusions, the silicate provided a deformable base in which the FeO was hardly deformed, but was squeezed to the surface of the inclusion and tended to break away (Fig. 9*h*).

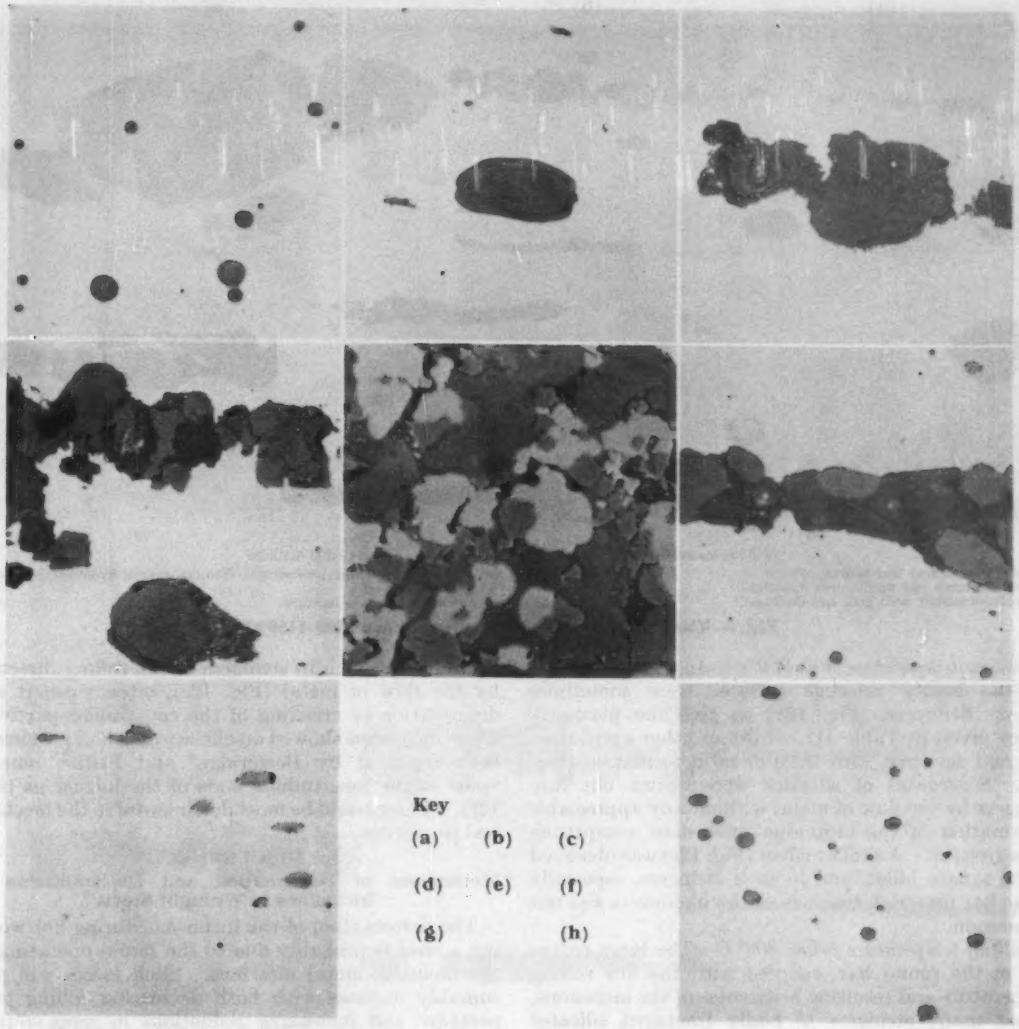
Owing to the reduced reduction in the square billet, most of the inclusions were either unfractured (Fig. 9*i*), or had fractured late in the deformation process (Fig. 9*j*). The results of the plasticity measurements are given in Table III.

Rolling temperature 900–950° C—In the bar material, most of the silicates had not deformed very much (Fig. 10*a*), as the results in Table III indicate, although some showed breaking up to have occurred towards the end of deformation (Fig. 10*b*), with much fragmentation and 'crazing' of the inclusion (Fig. 10*c*). Again, such an effect could be most detri-



(*a*) Spherical glassy silicate × 750
(*b*) Group of silicates × 750

Fig. 6—Cast RL.105. Inclusions in as-cast material



a–d and *g* bar material
e–f and *h* billet material

(*a*) Small undeformed FeO × 750
(*b*) Larger deformed FeO × 750
(*c*) Deformed and broken FeO × 750
(*d*) Increased plasticity of slag and breaking away of less deformable particles × 700

a–f rolling temperature above 1100–1150° C
g–h rolling temperature below 800° C

(*e*) Interphase cracking in deformed slag inclusion × 750
(*f*) Plastic silicate and relatively undeformed FeO × 750
(*g*) Small FeO starting to deform at low temperatures in bar × 750
(*h*) Small FeO showing less deformation in billet at low temperatures × 750

Fig. 7—Cast RL.106. Effects of rolling above 1100–1150° C and below 800° C

mental to the mechanical properties, but in the sections examined it was rarely observed and seemed confined to the larger inclusions. In many cases the inclusions were cracked and chipped with little or no deformation (Fig. 10*d*).

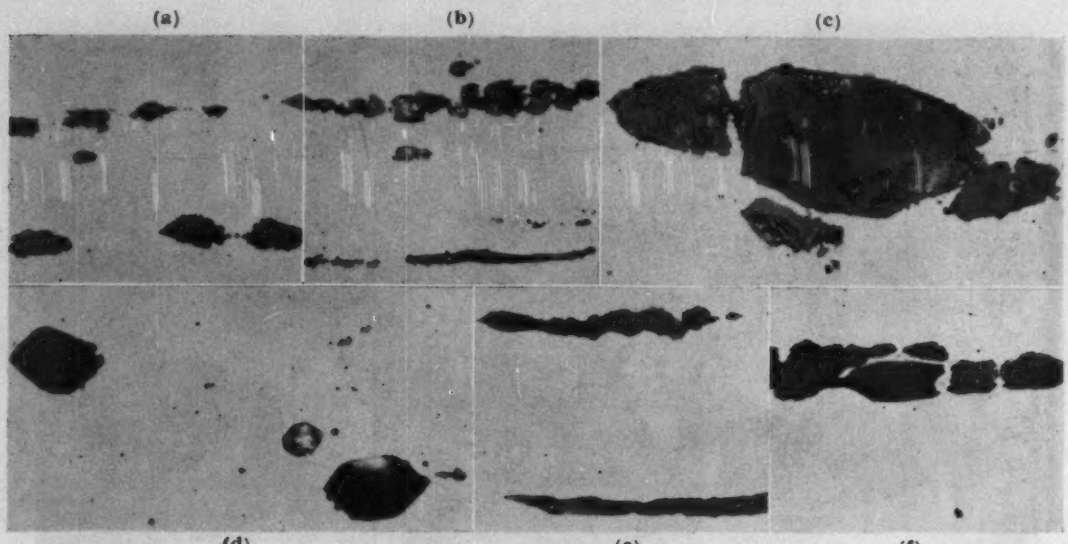
At the lower reduction, little deformation had occurred (Fig. 10*e*) and the majority of the larger inclusions had fractured by shearing (Figs. 10*f* and *g*). Sometimes the forces causing this shearing were so unbalanced as to cause the broken fragment to rotate and present a more streamlined shape to the general flow of deforming metal (Fig. 10*h*). In other cases, small pieces were chipped off the inclusion and carried along by the flow of metal to form a stringer (Fig. 10*i*).

Rolling temperature below 800° C—The heavy reduction in the bar material had caused the silicates to be extensively fractured without deformation (Figs. 11*a* and *b*) and the smaller duplex FeO–silicates were also not deformed.

In the billet material no deformation of the silicates occurred (Fig. 11*c*), although many were fractured as shown in Fig. 11*a*, and some were chipped with the fragments carried into a stringer by the flow of the metal (Fig. 11*d*).

Cast RL.105 $Si:O_2 = 1$

Attempts to roll this material above 1000° C resulted in complete break-up of the ingots.



a–d bar material

(*a*) Heavily deformed and broken silicate × 150
(*b*) Both fractured and unfractured inclusions × 750
(*c*) Fractured silicate with little deformation × 500

e–f billet material

(*d*) Fracture and tilting producing a diamond-shaped inclusion × 750
(*e*) Deformed silicates × 150
(*f*) Silicate starting to fracture × 150

Fig. 8—Cast RL.104. Effect of rolling above 1100–1150°C

Rolling temperature 900–950° C—In the bar material, the highly siliceous silicates were sometimes slightly deformed (Fig. 12*a*) to give the plasticity values given in Table III, whilst in other cases fracture had occurred with little or no deformation (Fig. 12*b*). Segregates of silicates were drawn out into stringers by the flow of metal without any appreciable deformation of the individual inclusions comprising the segregate. A similar effect (Fig. 12*c*) was observed in the square billet, and in such stringers, especially in the bar material, fracture of the inclusions was not uncommon.

Rolling temperature below 800° C—The large reduction in the round bar, coupled with the low rolling temperature and resulting brittleness of the inclusions, caused many stringers of badly fractured silicates (Fig. 12*d*), although many small isolated and undeformed inclusions were also seen. Segregates had been drawn out into stringers in the rolling direction by the flow of metal (Fig. 12*e*), often without any deformation or cracking of the constituent particles. Some inclusions showed an effect which had previously been reported by Betteridge[5] and Frith[2], namely voids at the longitudinal ends of the inclusions (Fig. 12*f*). These could be most detrimental to the mechanical properties.

DISCUSSION

Mechanism of Deformation and Dissemination of Inclusions in Wrought Steels

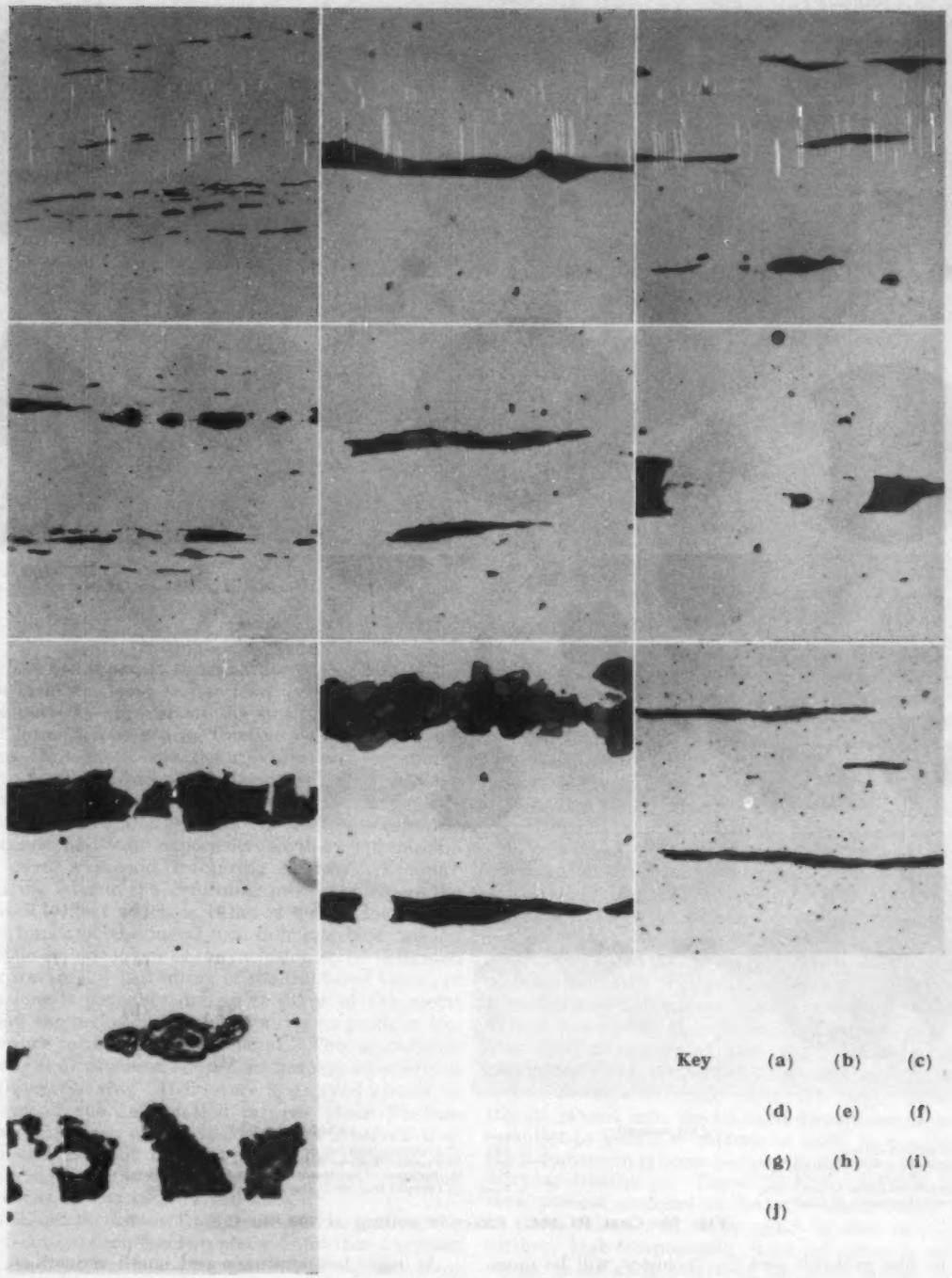
The deformation of the inclusions during hot working a steel is probably due to the forces operating at the inclusion/metal interface. Such forces will presumably increase with both decreasing rolling temperature and increasing reductions in cross-section. On the other hand, as the temperature decreases, the inclusion will become less plastic, so deformation

Table III

PLASTICITY MEASUREMENTS ON VARIOUS TYPES OF INCLUSION

Cast No.	Type of Inclusion	Above 1100–1150° C		1000–1050° C		900–950° C		Below 800° C	
		Bar	Billet	Bar	Billet	Bar	Billet	Bar	Billet
RL.106	Large FeO	0·024	0·081	0·027	0·086	...	...	...	...
	Small FeO	0·017	0·062	0·018	0·064	...	...	0·047	0·089
	Fractured FeO	0·024	0·104	...	...	...	...	...	...
	Slag	0·152	0·180	...	0·128	...	...	...	...
RL.104	Silicates	0·222	0·98	0·204	1·22	0·018	0·052	0·021	0·074
RL.105	Silicates	...	...	...	...	0·022	0·050	0·020	0·072

Values of zero plasticity were: ½-in. dia. bar material 0·017–0·019, average 0·018; 1-in. sq. billet material 0·050–0·073, average 0·062



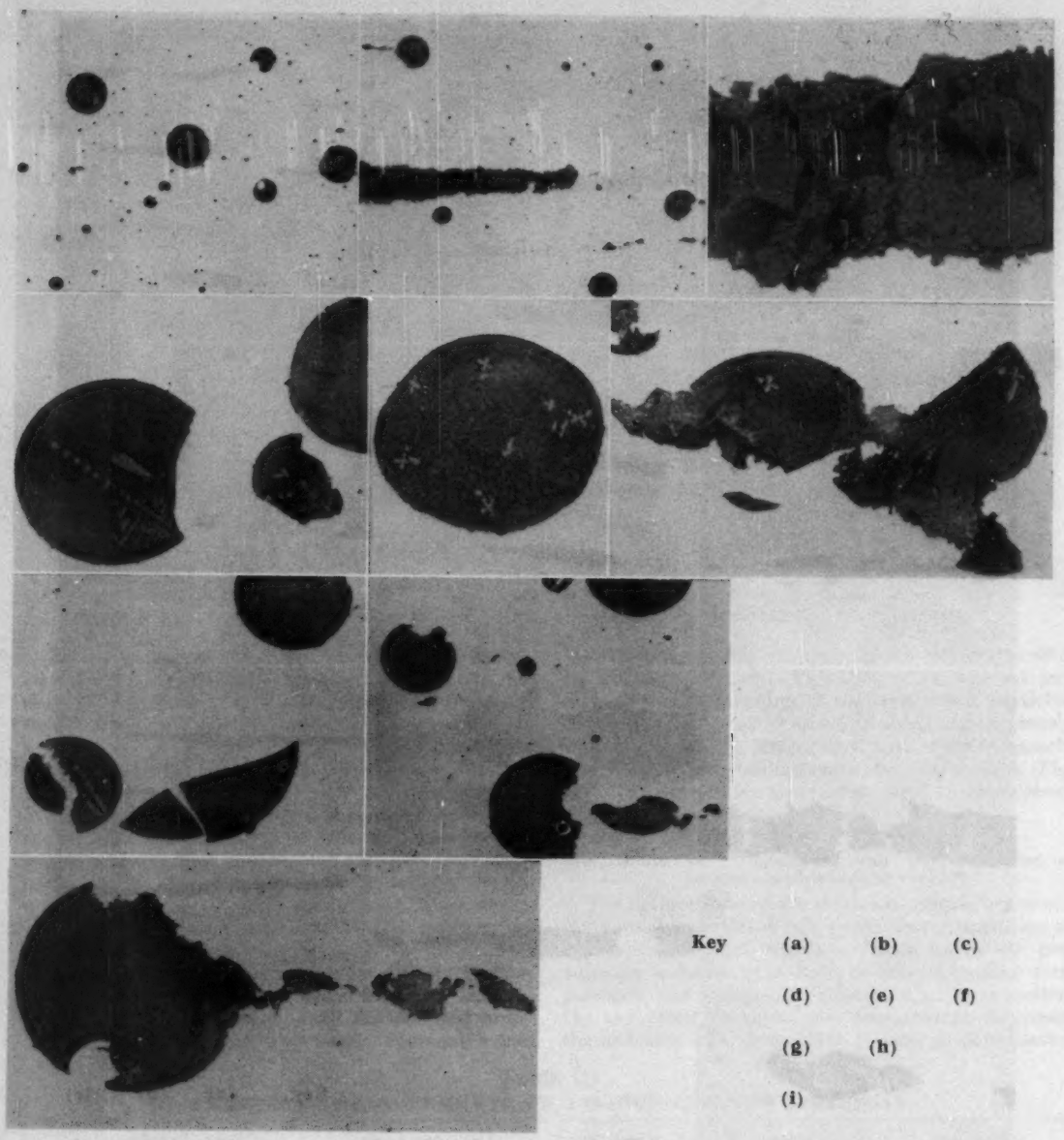
a–h bar material

(*a*) Extensive deformation and fracture of silicates × 150
(*b*) Unbroken silicate showing variable plasticity × 750
(*c*) Fracture occurring early during deformation with subsequent further deformation of silicates × 750
(*d*) Fracture occurring after considerable deformation—' fish-tail ' effect × 150

i–j billet material

(*e*) ' Fishtail ' effect × 750
(*f*) ' Fishtail ' effect × 750
(*g*) Fracture after completion of deformation × 750
(*h*) Undeformed oxides breaking away from surface of silicates × 750
(*i*) Unfractured silicate × 150
(*j*) Fracture at end of deformation × 750

Fig. 9—Cast RL.104. Effect of rolling at 1000–1050° C



a–d bar material

(*a*) Undeformed silicates × 150
(*b*) Deformation and chipping × 150
(*c*) Craze cracking in deformed silicate × 750
(*d*) Slight deformation and chipping × 750
(*e*) Slight deformation of silicate × 750

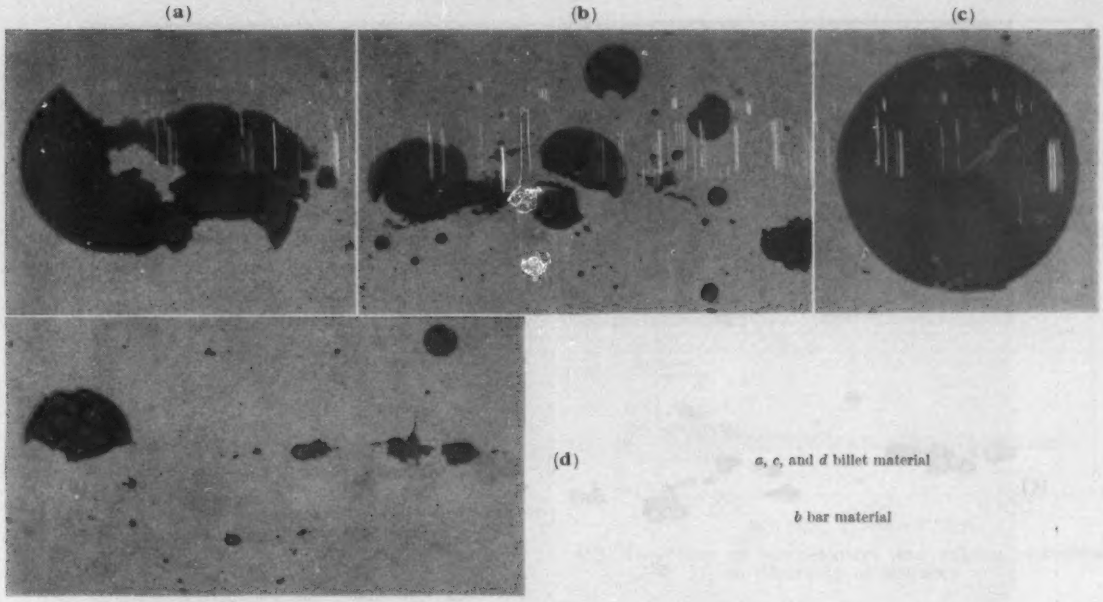
e–i billet material

(*f*) Fracture with no deformation × 750
(*g*) Fracture with no deformation × 750
(*h*) Rotation of fractured fragment by flow of metal × 750
(*i*) Chipped fragments displaced by flow of metal × 750

Fig. 10—Cast RL.104. Effect of rolling at 900–950° C

will be less probable and the inclusion will be more liable to fracture. Also, the less plastic the inclusion compared with the metal, the greater the differential forces at the interface during deformation, so that a shearing action is eventually set up which breaks the inclusion. An application of these concepts enables a rational interpretation to be made of most of the observed effects.

At high temperatures and small reductions, the silicates are deformed into long ellipsoidal masses, and sometimes are squashed by compression between the rolls. In a duplex inclusion, the more plastic phase is squeezed to the ends of the less plastic phase; when there is a relatively small amount of the harder phase, it is often found at the surface of the inclusion. In such a case, the forces at the inclusion/metal



(*a*) Fractured silicate × 750
(*b*) Group of fractured silicates showing no deformation × 150
(*c*) Undeformed silicate × 750
(*d*) Chipped silicate showing displacement of chippings by flow of metal × 750

Fig. 11—Cast RL.104. Effect of rolling below 800° C

interface can separate these harder particles from the main inclusion mass and so lead to dissemination of these particles throughout the steel.

At lower temperatures, fracture occurs at varying stages throughout the deformation process, giving rise to varying degrees of dispersion of the inclusions. If fracture occurs early in the deformation process, individual fractured blocks behave as separate inclusions and can experience further deformation and even a second fracturing process. Fracture occurring later in the deforming process produces the 'fishtail' effect which is believed to be due to the large forces at the metal/inclusion interface causing only the outside layers of the inclusion to be deformed after fracture. The tilting of the fractured blocks of inclusions is probably due to the flow of the metal around the inclusion turning it so as to produce less resistance to the flow of the metal. This is probably the origin of diamond-shaped inclusions, especially if they were silicates. If fracture is delayed almost to the end of the deformation process, clean fracture surfaces are seen and it is sometimes observed that the metal has not filled in the space between the fractured blocks. Also extensive 'crazy' cracking can occur in the larger inclusions.

In duplex inclusions, fracture often occurs along the interfaces between the two phases, and this, together with the interface forces between metal and inclusion, can result in a widespread dispersion of the fragments.

At still lower temperatures at which the inclusions are much less deformable, the forces at the inclusion/metal interface cause a shear fracture, often diametrically across the inclusion, with little or no apparent deformation. The two halves of the fractured inclusion may then be displaced relative to one another, and the debris, from the fracture or chipping which also occurs, may be drawn out by the flow of metal into a stringer in the direction of rolling. Broken fragments of inclusions may also be re-aligned so as to produce less resistance to the flow of metal by presenting a more streamlined shape.

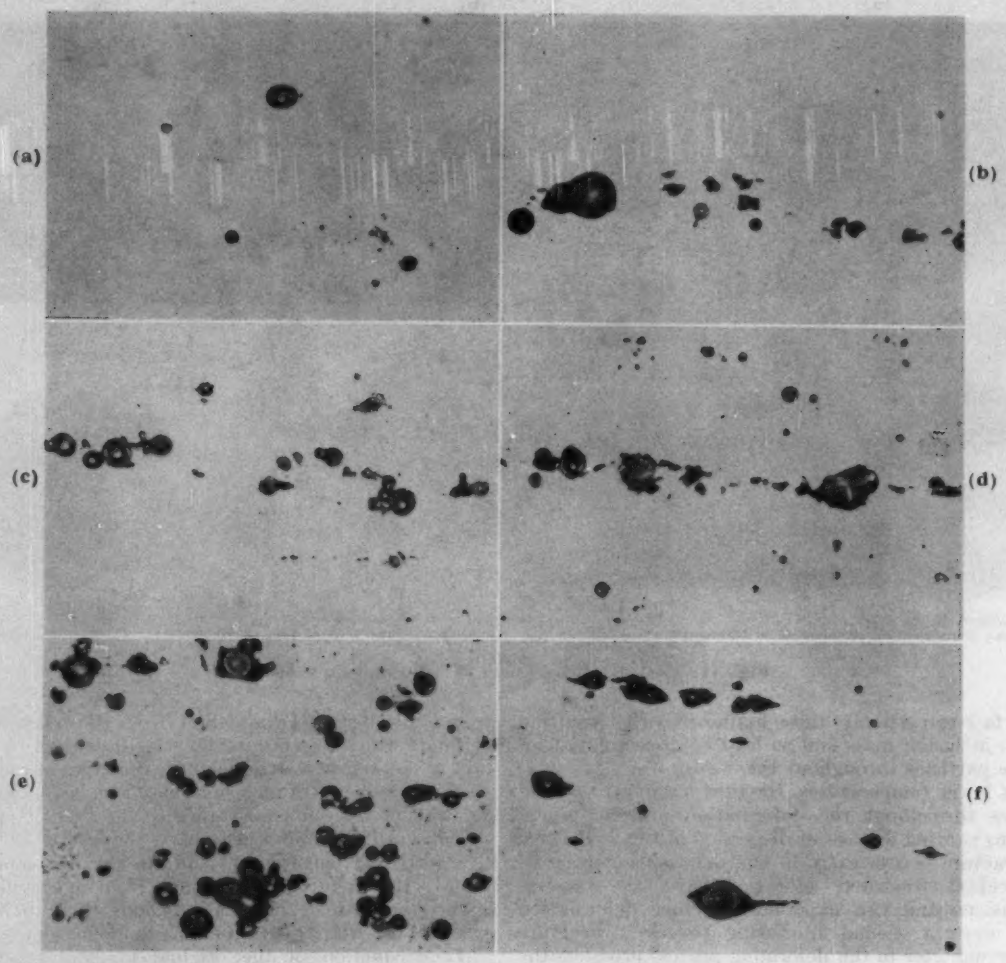
A good example of the effect of the general flow of the metal is the production of a stringer from an irregularly shaped segregate of siliceous inclusions, the individual particles of which are otherwise undeformed.

The reduction of the original ingot during hot working will also be of importance. Small reductions cause less probability of fracture than larger ones, and the deformation produced is less. Particle size also has an effect, presumably due to the forces at the metal/inclusion interface. Small particles tend to deform less readily than do larger ones, and generally only start to deform at low temperatures and large reductions when the forces acting on them are large.

To successfully break down the larger injurious silicate masses into less harmful dispersions, it seems essential to promote fracture as early as possible in the deformation process, perhaps by a low-temperature working treatment. These fractured particles may then possess undesirable features which might act as stress raisers and these could be overcome by a further high-temperature working process which would cause each fragment to be deformed as an individual inclusion. Repeated deformation of the steel would have obvious advantages.

Effect of Temperature and Reduction during Working on the Plasticity of Inclusions

It will be seen from Figs. 13 and 14 that the plasticity values are higher for the lower reductions



a and *b* bar, *c* billet } rolled at 900–950° C

(*a*) Slightly deformed silicate × 750
(*b*) Segregate of undeformed and broken silicates elongated in direction of rolling × 750
(*c*) Segregate drawn out by flow of metal × 750

d and *e* bar, *f* billet } rolled below 800° C

(*d*) Heavily fractured inclusion drawn out into stringer × 750
(*e*) Segregate drawn out into stringer × 750
(*f*) Voids at longitudinal ends of silicates × 750

Fig. 12—Cast RL.105. Some effects of rolling at 900–950° C and below 800° C

(billet) than for the higher reductions (bar). Apart from the considerations to be discussed later, this is due to the fact that the plasticity of the inclusion as measured by the ratio of the deformation in the inclusion to that in the steel is always larger for the lower reductions because of the smaller length:width ratio of the steel at those lower reductions. In Figs. 13 and 14, the values corresponding to no plasticity of the inclusion (*see* footnote to Table III) are also incorporated, for both bar and billet material.

Iron oxide—The results of the plasticity measurements are shown as a function of deformation temperature in Fig. 13. The plasticity of FeO is always more at low reductions than at high reductions. Apart from the reason already given, this apparent anomaly may be due to:

(i) FeO deforming easily at first but work-hardening rapidly

(ii) As the spheres become ellipsoids, they offer less impedence to the flow of metal so that the interfacial forces causing deformation decrease and the plasticity apparently decreases.

The effect of particle size on the deforming forces causes the large particles to deform more than the smaller ones at any given temperature, but at low temperatures when the forces increase, the plasticity of the small particles also increases despite the reduced temperature. In general, it was observed that the fractured FeO showed slightly increased plasticity over the unfractured FeO.

Slag associated with iron oxide—In all cases, the slag was much more deformable than the FeO, owing to the silicate acting as a carrier for the embedded FeO (Fig. 13). The plasticity, however, was not so great as for the silicate alone, as shown by a comparison between Figs. 13 and 14.

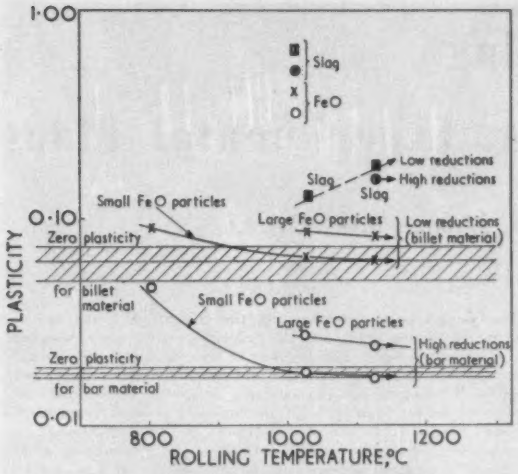


Fig. 13—Effect of temperature and rolling reduction on plasticity of FeO and slag

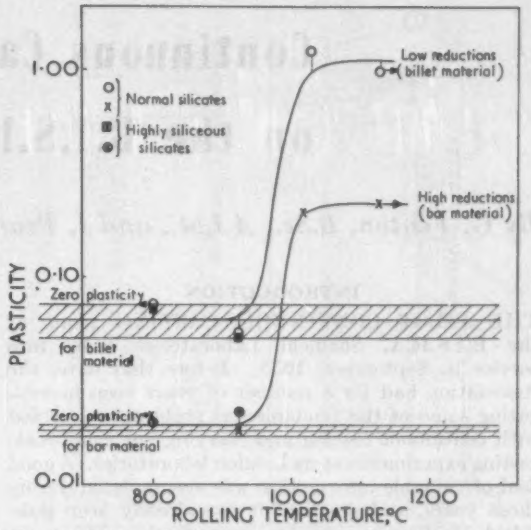


Fig. 14—Effect of temperature and rolling reduction on plasticity of silicates

The plasticity of the slag decreases with decreasing temperature, presumably owing to the marked decrease in plasticity of the silicate which more than offsets the effect of increasing interfacial forces.

Predominantly silicate inclusions—Again, the smaller reductions produce an apparently increased plasticity for reasons already given. The results in Fig. 14 show that for a given reduction, the plasticity remains constant down to a rolling temperature of 900–1000° C, below which it abruptly decreases to a value corresponding to no plasticity. This is due to the very rapid decrease in plasticity of glassy silicates as the temperature decreases, and this sudden decrease in plasticity is accompanied by brittle fracture of the inclusions.

The general observation was made that the broken silicates appeared less plastic than those which did not fracture. This emphasizes the wide variation in plasticity and fracture characteristics in inclusions of nominally the same type, possibly caused by segregation of the deoxidant and a consequent compositional variation in the inclusions.

Highly siliceous inclusions—Because they were small, these inclusions did not deform until a low temperature despite the decrease in plasticity. The value of the plasticity is then of a similar order to that of the normal silicates, and it may be that the very small deformations induced by high interfacial forces are relatively insensitive to composition changes. Indeed, the actual values of the plasticity are so low as to indicate almost no deformation.

CONCLUSIONS

An examination has been made into the deformation and dissemination of non-metallic inclusions during rolling, which has been supplemented by quantitative data on inclusions in the Fe–O_2–Si system.

The mechanism of the deformation and fracturing processes has been interpreted on the basis of the forces set up at the metal/inclusion interface (by the hot working) and the relative movement of metal and inclusion at that interface.

The major conclusions drawn are:

(1) Fracture of the inclusions is necessary in order to disperse the larger detrimental inclusions into smaller, less harmful particles.

(2) Fracture occurs at low deformation temperatures or large hot-working reductions.

(3) Silicate particles rapidly lose their plasticity at about 1000° C when fracture readily occurs.

(4) Iron oxide particles appear to become increasingly plastic as the temperature decreases.

(5) It is suggested that multiple hot working, with intermediate reheatings, would be better than all the hot work being carried out with only one reheating.

It is intended to extend the work described to investigate a system of more practical interest, namely iron oxygen alloys deoxidized with both Al and Si. Such work, however, will necessitate a preliminary survey of the types of inclusion in this system.

Acknowledgments

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Continuous Casting on the B.I.S.R.A. Experimental Plant

By G. Fenton, B.Sc., A.I.M., and J. Pearson, M.Sc., Ph.D., F.R.I.C.

SYNOPSIS

The design and operation of the B.I.S.R.A. experimental continuous-casting plant and the principle of the spring-mounted mould are described. The product of the plant has been sample casts for assessment of external and internal quality and workability. The ingots are characterized by good surface and comparative freedom from segregation; central looseness is sometimes present, depending on casting conditions, but in every case it has been eliminated on hot-working. Because the product has a cast structure it requires hot-working to give satisfactory mechanical properties; the amount of reduction in cross-sectional area to achieve these varies from 50% to 85%. 1557

INTRODUCTION

THE PILOT CONTINUOUS-CASTING plant at the B.I.S.R.A. Sheffield Laboratories came into service in September, 1955. Before that date, the Association had for a number of years been investigating some of the fundamental problems connected with continuous casting and carrying out small-scale casting experiments at its London laboratories. A good deal of valuable information was accumulated during those years, and much of it has already been published by Savage and his co-workers.[1] The most important outcome of this work was the development of the spring-mounted mould,[2] which has been a marked feature of the B.I.S.R.A. continuous-casting system.

Although this earlier work was of great value, it became increasingly obvious that casting experiments on a larger scale were essential for the further development of the process, and this led to the construction of a pilot plant at the Sheffield laboratories. The present paper is concerned with this particular plant; it is intended to describe the design of the plant and then to discuss the results obtained on it.

DESCRIPTION OF THE PLANT

The plant is located in the experimental melting shop at the Sheffield Laboratories and is provided with steel from a ½-ton basic electric-arc furnace. With the limited quantity of metal available, the plant could be kept quite simple and it is, in fact, designed on a semi-continuous basis to cast one length of ingot of about 22 ft.

When the melting shop was planned it was decided to allow for the eventual erection of a continuous-casting plant by giving the shop adequate height, and the track of the overhead crane is 35 ft above ground level. To permit the ladle to be brought into position by the overhead crane, the top platform of the plant was erected 25 ft above ground level, but a pit about 10 ft deep was also provided, giving an effective overall plant height of 35 ft. A photograph of the plant in operation is shown in Fig. 1.

The Ladle

The ½-ton ladle is bricked with a course of insulation behind the main lining in order to reduce heat losses. Immediately after teeming, the ladle is covered with an insulated lid, for the same reason. At present a conventional stoppered ladle is used, but experience has been gained of lip-pouring ladles with slag dams. Both types of ladle have advantages and disadvantages which have to be considered carefully when designing a production plant; on a relatively small experimental plant, the short pouring times required make this question less vital, and the stoppered ladle now used was adopted largely from the point of view of convenience. Before use, the ladle is preheated with a gas burner and is at about 900° C at tapping.

The Tundish

The ladle discharges into a tundish, which is a simple box fitted with stopper and nozzle at one end. The tundish is lined with a high-quality firebrick and also has a backing of insulating brick to reduce heat losses. The firebrick is of higher quality than that of the ladle because of the higher preheat involved; a temperature of 1350° C is attained, again by gas burner, which is maintained at full pressure until teeming begins. During teeming, a low flame is usually maintained to prevent too much oxidation of the metal. The ladle operator, by using the stopper for short but frequent periods, maintains the level in the tundish as constant as possible in order to minimize flow variations from the tundish nozzle. The tundish stopper is controlled by the mould operator, who also controls the withdrawal rate of the cast ingot. As far as possible, however, the tundish nozzle is left fully open to ensure a good casting stream. Usually this is quite feasible, provided that the ladle teeming is well controlled and the tundish nozzle diameter has been correctly chosen to match the projected withdrawal rate.

Here it would be advisable to point out one particular difference between an industrial plant and the experimental plant. In the former, the variations in teeming rate from the tundish will normally be

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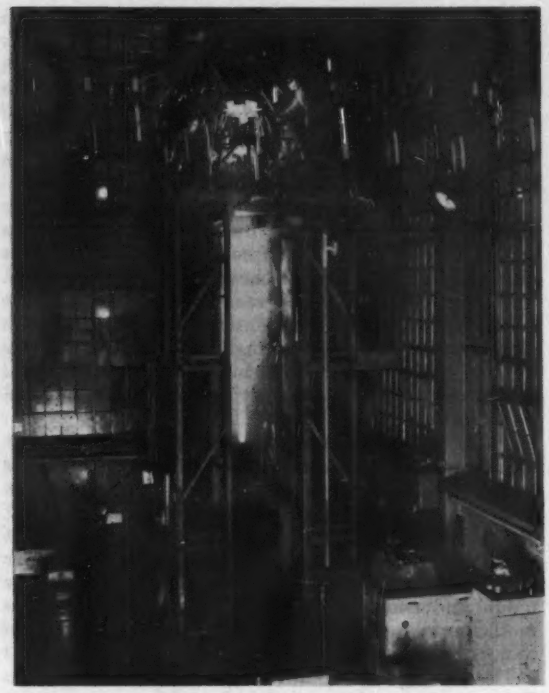


Fig. 1—B.I.S.R.A. experimental plant in operation

taken care of by the mould operator making a slight adjustment to withdrawal rate, whereas in a research plant it is obviously desirable to maintain a constant withdrawal rate or one which is only altered in certain predetermined stages. In other words, in the industrial plant the flow rate from the tundish determines the withdrawal rate, whereas in the experimental plant the withdrawal rate is predetermined and the tundish flow rate is controlled accordingly.

In addition to the simple design of tundish just described, B.I.S.R.A. has also used very effectively another type of tundish, a ' heated nozzle ' tundish[3] (Fig. 2). Essentially this type of tundish consists of two chambers, the upper of which comprises the tundish hearth and the lower a heating chamber through which the refractory down-tube containing

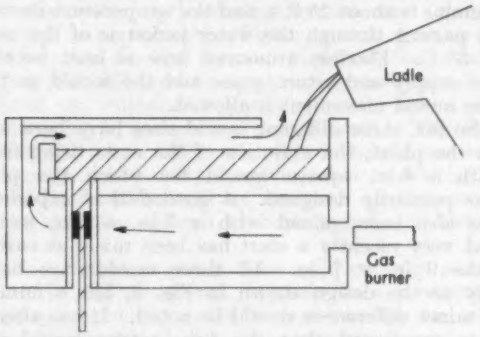
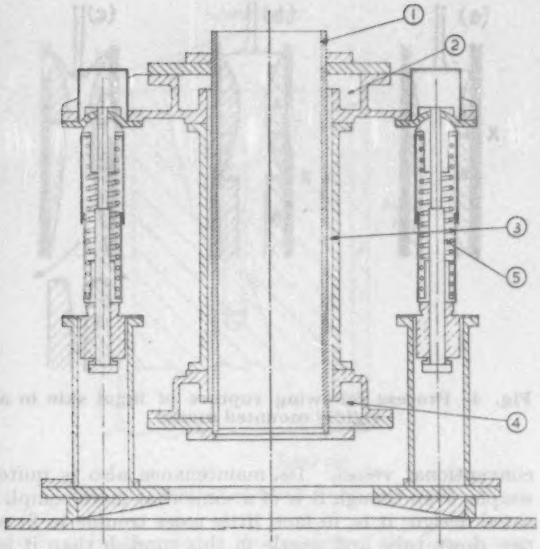


Fig. 2—B.I.S.R.A. heated-nozzle tundish



1. Copper mould tube
2. Water outlet manifold
3. Annular water jacket
4. Water inlet manifold
5. Telescopic spring mounting

Fig. 3—B.I.S.R.A. continuous casting mould, showing spring suspension

the nozzle passes. By means of this design, the nozzle can be preheated to very high temperatures, even exceeding the melting point of steel, and the heating can be maintained throughout the cast so that the danger of premature freezing in the nozzle is practically eliminated. Because of the high temperatures involved, high-quality refractories are even more essential than in the conventional tundish. The nozzle is usually of zircon, or occasionally magnesite, and the down-tube of silicon carbide or plumbago. A high thermal conductivity is, of course, an asset when external heating is employed.

The down-tube serves another very useful purpose in providing a greater head of metal above the nozzle, which minimizes the effects of variation of level in the main hearth. This tundish, then, provides a more constant flow than the conventional vessel, and this effect can be made even more pronounced by fitting a stopper which is seated, in effect, into the top of the down-tube. The use of this stopper in the hands of an experienced operator can cut down flow variations to negligible levels, whilst the presence of the down-tube between stopper and nozzle removes any danger of the bad stream often associated with a partly closed nozzle.

The elimination of the danger of premature freezing in the nozzle means that it is possible to use a nozzle of much smaller diameter than could be considered for a conventional tundish. This could be important with certain alloy steels which can be cast only slowly and into relatively small sections; it has also obvious advantages in a research plant where wide variations in casting rates are required.

Although more costly, this heated-nozzle tundish has a number of very definite advantages over the

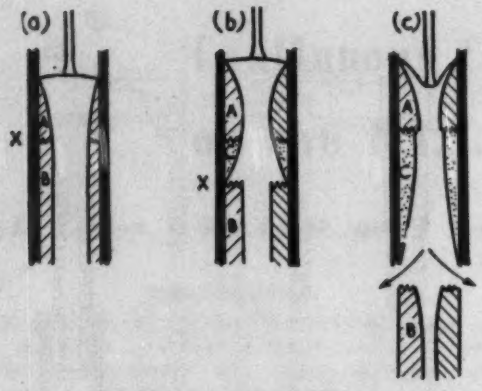


Fig. 4—Process following rupture of ingot skin in a rigidly mounted mould

conventional vessel. Its maintenance also is quite simple, even though it is of a somewhat more complicated design; it is, in fact, little more trouble to fit a new down-tube and nozzle in this tundish than it is to fit a new nozzle in a conventional tundish.

The Mould

Next in line travelling down the plant is the unit which is the unique feature of the B.I.S.R.A. process—the mould itself. The 4-in. square mould is shown diagrammatically in Fig. 3. The mould tube is drawn from electrolytic copper, and is 19 in. long with a wall thickness of $\frac{1}{4}$ in. It is surrounded by a water jacket which leaves an annulus $\frac{1}{4}$ in. wide connecting with bottom and top manifolds which have four inlets and four outlets respectively. The tube and water jacket are mounted on compression springs contained in the telescopic pillars shown in Fig. 3. This arrangement allows the mould to move vertically downwards, against the restoring force of the springs, for a distance of 2 in.

The idea of mounting the mould flexibly (e.g. on compression springs as mentioned above) was developed very early in B.I.S.R.A.'s research programme as a means of preventing rupture of the newly formed skin in the mould. The earlier casting experiments were carried out in a mould mounted rigidly, and it was soon obvious that one particular difficulty in continuously casting steel was the continuous stripping of the ingot skin without rupture occurring. For the first few seconds after the start of solidification, the skin is very thin and, being at a temperature only just below the solidus, has very little strength. It is also in fairly intimate contact with the mould wall, as little contraction will have occurred at that time. If the mould is mounted rigidly, any frictional forces set up will be directly opposed to the withdrawal force and will act on this weak skin; rupture will obviously occur if the breaking strength of the skin is exceeded. This is illustrated in Fig. 4, where the thickening of the ingot skin is shown in exaggerated form. At point *X* (Fig. 4*a*) a rupture is assumed to have occurred as a result of friction between portion *A* of the ingot and the mould. Portion *B* continues to travel down the mould (Fig. 4*b*), causing an ever-widening gap between portions *A* and *B*. Metal flows into this gap at *C* and begins to solidify, but rarely becomes completely welded to portion *B*, because of the latter's continued downward movement. Thus the rupture travels down the mould, eventually reaching the bottom (Fig. 4*c*), when the molten metal breaks out and the process stops.

If the mould is mounted on springs, however, any friction between skin and mould tends to pull the mould downwards. The force on the skin is then only the restoring force of the springs. As the mould moves downwards, this restoring force increases gradually; at the same time, the skin is being rapidly chilled, thickened, and strengthened, and is tending to shrink away from the mould, so that friction decreases. The mould then returns to its normal position.

The springs used must be carefully chosen so that at no time does the restoring force exceed the breaking strength of the skin. When casting 4-in. square ingots in carbon or low-alloy steels, springs with a modulus of 50 lb/in. are used. With a mould movement of 2 in. the maximum restoring force is 400 lb. Under normal casting conditions, however, it is unusual for mould movement to exceed $\frac{1}{2}$ in., and generally the mould exhibits a gentle floating motion during the cast.

The oil-ring is placed around the top of the mould. This consists quite simply of a thin copper tube provided with outlets extending just over the top of the mould. Rapeseed oil is used as the lubricant, and is fed to the oil-ring by a positive displacement pump actuated by a small variable-speed motor. The oil feed can be varied during a cast but is usually maintained at about 15 cm^3/min, issuing as a thin continuous trickle down the mould wall. A vegetable oil is preferred to a mineral oil, as the former burns with a transparent flame which does not obstruct the operator's vision.

The mould cooling water is supplied from a recirculating system which incorporates a reservoir of 3000 gal, large enough to ensure that there is no increase in temperature in the inlet water during a cast. The water is circulated by means of a 5-h.p. pump, capable of supplying 300 gal/min. In practice, however, the restriction caused by the narrow annulus makes it difficult to obtain flows above 250 gal/min. At this rate of flow the velocity of the water in the annulus is about 25 ft/s, and the temperature increase on passing through the water jacket is of the order of 3° C. Flexible armoured hose is used between the supply and return pipes and the mould so that free mould movement is allowed.

So far, three different mould sizes have been used on the plant, the majority of the casts being made with a 4-in. square mould for which the plant was primarily designed. A good deal of experience has also been gained with a 3-in. square mould, and very recently a start has been made at casting slabs 9 in. × $\frac{3}{4}$ in. All three moulds are basically to the design shown in Fig. 3, but a number of minor differences should be noted. It has already been mentioned that the 4-in. square mould is a drawn tube, $\frac{1}{4}$ in. thick and 19 in. long. Because of

difficulties at the time of manufacture, the 3-in. square mould was drawn to $\frac{3}{8}$ in. thickness, and is also 19 in. long. Difficulty was also anticipated in drawing the slab mould tube and so it was made in two halves, accurately machined and bolted together along flanges extending the full length of the narrow sides. This tube is $\frac{1}{4}$ in. thick and 22 in. long. The first casts in the slab mould, however, indicated that this extra length was unnecessary and arrangements have now been made to reduce its length to 16 in.

After 68 casts had been made in the same 4-in. square mould, the tube was removed and carefully measured to determine whether any significant distortion had taken place. It had been noticed before this that there was a gradual and very slight reduction in overall heat transfer in the mould from cast to cast. Its effect could not be detected in the quality of the product nor in the casting operation; there was, if anything, a slightly wider variation in friction, as measured by the mould movement during casting. The measurement of the mould tube showed these effects to be caused by a slight inward bulge of the mould faces at meniscus level, reducing the cross-sectional dimension by about 0·03 in. In other words, the mould had acquired a small outward taper beneath meniscus level, causing the newly-formed skin to separate earlier from the mould, with consequent reduction in overall heat transfer. Friction tended to be higher or lower than normal, depending on the position of the meniscus in relation to the bulge in the mould tube.

The cause of this distortion appears to be permanent set in the copper due to differential expansion. At this time, the mould cooling water was taken from the mains and a maximum flow of only 100 gal/min was obtainable. In addition to the longitudinal expansion of the tube, which is allowed for by means of an expansion joint between tube and assembly, it is apparent that the temperature gradient through the mould wall will cause a differential expansion, which will result in the mould face bulging inwards, aided by the pressure of the water in the annulus. If the temperature of the copper exceeds about 250° C, a significant permanent set can occur quite easily and subsequent casts will, up to a point, tend to have a cumulative effect.

To avoid this danger, it is obvious that the mould wall temperature should be kept as low as possible, and the water recirculating system and pump, allowing a considerably higher water flow rate, were installed for this reason. However, the inward bulging will still tend to occur during each cast (but without the cumulative permanent set) unless the mould tube is adequately strengthened. The slab mould will be modified with this in mind, and will be provided with a rigid water jacket to which the mould tube will be tied by means of spacing strips in the annulus, secured to both jacket and mould tube.

Although these precautions will prolong mould life, it is still considered desirable in a production plant to record the water temperature rise for each cast. If this falls below a predetermined level, the tube should be removed and re-dressed before being put back into service. Re-dressing of the 4-in. square mould tube brought about an immediate increase in overall heat transfer to its original level.

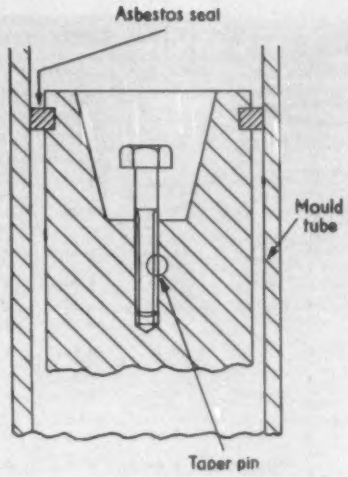


Fig. 5—Detail of dummy head in mould

This type of spring-mounted mould assembly has been found to be a simple and effective means of overcoming skin rupture. As already mentioned, improvements in design are continually being made without, however, any change to the basic principle. The mould has a great advantage in being a completely independent unit, which makes the changing of moulds a very simple operation taking only about 15 min. It has a further great asset in the very good ingot surfaces produced; this will be discussed later.

The Dummy Bar

The dummy bar used on the plant is only 5 ft long and is fitted with a head about $\frac{1}{4}$ in. smaller than the mould in cross-sectional dimension (*see* Fig. 5). Near the top of the dummy head a groove is machined, packed with asbestos string to form a good seal when the head is brought up into the mould to start the cast. The top of the head is recessed in the centre to form a splash cup, at the bottom of which a mild-steel bolt is fitted to act as a key on which the ingot freezes. The bolt is a loose fit in a hole drilled vertically downwards from the bottom of the splash cup, and is held in position by a horizontal pin engaging in a groove previously cut in the bolt. To free the ingot from the dummy bar at the end of casting, all that is required is to knock out the horizontal pin.

The dummy heads for the three types of mould used are all similar in design, except that the head for the slab mould is fitted with two mild-steel bolts and pins and has a much shallower recess.

Guide Rolls

Immediately beneath the top working platform, four sets of guide rolls are fitted at approximately 9-in. intervals. Each set consists of four rolls, arranged in a box formation, and they are designed to ensure that the axis of withdrawal is maintained as constant as possible. They play little part during

Table I

TYPES OF STEEL CAST ON B.I.S.R.A. EXPERIMENTAL PLANT

Quality	Analysis, %						Section	Casting Speed, in./min
	C	Si	Mn	S	P	Others		
En. 2D	0·21	0·23	0·63	0·039	0·040		4 in. sq.	49
En. 3A	0·18	0·26	0·50	0·020	0·030		4 in. sq.	46
En. 5	0·33	0·21	0·71	0·040	0·040		4 in. sq.	48
	0·35	0·14	0·60	0·030	0·030		9 × 1¾ in.	77
En. 8	0·36	0·35	0·80	0·040	0·040		4 in. sq.	45
En. 18	0·45	0·18	0·80	0·018	0·040	0·85% Cr	4 in. sq.	48
	0·35	0·19	0·73	0·043	0·040	0·99% Cr	3 in. sq.	65
En. 34	0·20	0·14	0·57	0·028	0·050	1·89% Ni 0·30% Mo	4 in. sq.	49
En. 45	0·50	1·78	1·00	0·020	0·020		3 in. sq.	65
							3 in. sq.	144*
En. 56A	0·07	0·32	0·69	0·041	0·029	14·0% Cr	4 in. sq.	40
File steel	1·20	0·53	0·20	0·030	0·028	0·50% Cr	4 in. sq.	36*

* With secondary cooling

the early part of a cast but are important towards the end, when the unsupported length of ingot is relatively great and might tend to bend under its own weight. Any excessive departure from the axis of withdrawal would result in shear forces on the skin of the ingot just leaving the mould and possible failure. A certain amount of movement away from the axis can be tolerated as the spring suspension of the mould allows some lateral movement, but guide rolls are necessary to prevent this movement becoming excessive.

Secondary Cooling

During the earlier period of working on the plant, it was not possible to apply any secondary cooling to the ingot owing to insufficiency of supply from the town water main. Most of the results discussed later in this paper were obtained during this period.

With the installation of the recirculating system, however, it has been possible to make a start on investigating the effects of secondary cooling. The short dummy bar permits a spray zone only about 3 ft long, but modifications will shortly be made to increase this considerably. Even this short zone, however, has already shown the value of secondary cooling, and that it is possible to increase the casting speed considerably without detriment to ingot quality.

The sprays used are of the fishtail type, giving a wide flat jet, and are set just sufficiently far back from the ingot surface for the spray width and ingot width to coincide. There are four banks of sprays, one to each ingot face, and at present each bank holds 23 sprays set about 1½ in. apart vertically. The total spray volume passed is about 30 gal/min.

Withdrawal System

This is the part of the pilot plant that differs most widely from a production plant, which will normally be fitted with powered withdrawal rolls and ingot cut-off mechanism. On the pilot plant, such items are unnecessary, as the full ladle capacity can be cast into one length, and withdrawal is carried out by a simple lift system. Below the top working platform, the structure is in effect built around a lift shaft. The dummy-bar is mounted on a lift platform which can be moved on guides from top to bottom of the plant. The movement is effected by wire ropes, passing over pulleys at top and bottom of the shaft and thence to a winding drum, driven by a 3-h.p. motor through an infinitely variable gear. This enables the speed to be varied between zero and 15 ft/min; it can be changed during casting and can also be pre-set to any required level.

The maximum travel of the lift is 28 ft. After the end of casting, the ingot must be lowered below the guide rolls for removal from the plant, so that the maximum ingot length permissible is 22 ft. Trip switches, actuated by the lift platform, are fixed in the shaft and ring warning bells when the 22-ft length is approached; difficulty in ingot removal would be experienced if the ingot length were allowed to exceed this figure.

Between ground level and the top working platform, two intermediate platforms extending round three sides of the lift shaft have been installed. They serve to hold the driving mechanism of the withdrawal system and to allow ease of maintenance, but are never manned during a cast. The fourth side of the lift shaft is freely accessible, to allow the ingot to be removed from the plant.

Ingot Removal

After casting, the ingot is lowered out of the mould and withdrawn down the shaft until the top is free from the guide rolls. During this period, the ingot is supported by a special rig fixed further down and across the lift shaft. The ingot is normally left to cool in this position before removing it from the plant. Immediately beneath the working platform, a small bogey carrying a lifting sling is located on rails extending outwards from the centre of the platform to a point just beyond its edge. When cool, the ingot is held in the bogey sling, freed from the dummy

head by removal of the pin, and the bogey moved outwards to the edge of the plant. From this position the ingot can be taken up by the overhead crane and removed.

Plant Operation

Before each cast, the plant alignment is checked, the dummy bar is brought up into the mould, and the seal is made. Meanwhile the ladle and tundish are being preheated, over a period of about 3 h. As the loss of metal temperature in the small ladle is about 5° C/min, the furnace tapping temperature is usually about 10–15° C higher than would be used for conventional ingot casting, to allow for the time required to carry the ladle to the top of the plant. When the ladle reaches the top platform, a dip temperature is taken and casting is not started until the desired temperature is reached.

When ready for casting, the tundish burner is turned down and the ladle operator fills the tundish, aiming to maintain as constant a level as possible. As soon as a few inches head of metal is obtained in the tundish, the mould operator opens the tundish nozzle and starts to fill the mould, starting the withdrawal when the normal level is reached. The same operator also starts the flow of lubricating oil and controls the quantity as desirable. As already mentioned, in the experimental casts the withdrawal rate is maintained as constant as possible, so that the mould operator's main task is to keep a steady flow from the tundish. A third operator stands by during the cast to remove, by means of a wire rod, any tundish slag which may enter the mould.

When the warning bell rings, indicating the 22-ft length, the mould operator closes the tundish stopper and, after a short period, withdraws the ingot completely from the mould. Meanwhile the third operator positions a special launder beneath the tundish so that it can be drained into a slag pot.

The operators, and particularly the mould operator, naturally require experience before full proficiency is attained. Once the necessary experience is gained, however, and with good routine maintenance and careful setting up of the plant prior to casting, the whole operation works quite smoothly.

CHARACTERISTICS OF THE INGOT

During the two years of operation, the plant has been very largely concerned with the production of steel to certain specifications, and the ingots have been supplied to member firms of B.I.S.R.A. for their own appraisal. The information gained from these studies is collected here, together with the results of B.I.S.R.A.'s own examinations, as a general summary of the quality and behaviour in practice of continuously cast steel. The range of steels cast is shown in Table I; this range is not comprehensive and with one exception (14% Cr steel) is confined to plain carbon and low-alloy steels in the fully killed state. At the same time, practice and procedure have been steadily improved so that many of the defects found in the earlier ingots have now been largely eliminated by closer control of the process.

The casting speed figures shown in Table I are those at which it was felt that satisfactory quality had been obtained. It must be emphasized here, however, that only in the two instances shown was it possible to apply any secondary cooling to the ingot, for the reasons previously mentioned. The experience with the silico-manganese steel, where secondary cooling allowed the casting speed to be more than doubled whilst still maintaining satisfactory quality, indicates that it will be possible to increase considerably the speeds shown in Table I, now that secondary cooling is installed.

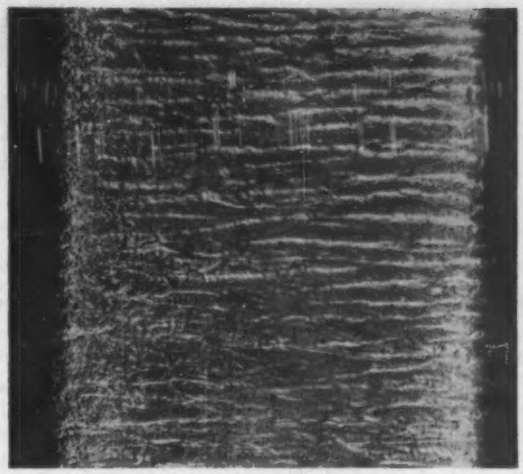


Fig. 6—Typical ingot surface

Ingot Surface Condition

The surface of ingots continuously cast in the spring-mounted mould is extremely good, showing a series of ripples normal to the longitudinal axis of the ingot. These ripples may be compared with those found on the surface of a conventional ingot cast in a well dressed mould in good condition. Their spacing tends to increase with the speed of withdrawal, and at all but very low speeds, where there is a danger of cold shuts being formed, they are not sufficiently deep nor re-entrant to cause difficulty on subsequent hot working. The prevention of skin rupture in the mould by the spring mounting means that the surface marks often associated with this defect are avoided. Figure 6 shows a typical ingot surface.

It is possible for small quantities of slag to reach the mould from the tundish. In normal operation, the operator can remove these particles of slag from the meniscus with wire rods before the slag becomes enfolded into the skin. If some slag should be entrapped in the ingot skin, it may remelt below the mould and cause a bleed mark on the ingot surface and in severe cases can cause the liquid core to drain out. High-grade refractories in the tundish are necessary for this reason.

Surface pinholes have occasionally proved troublesome and are usually associated with the use of excessive lubricant and with casts which have a high hydrogen content. Such pinholes become oxidized during reheating operations and produce seams on the finished bar. This defect has been largely obviated by careful regulation of the quantity of lubricant and by control on the steelmaking procedure.

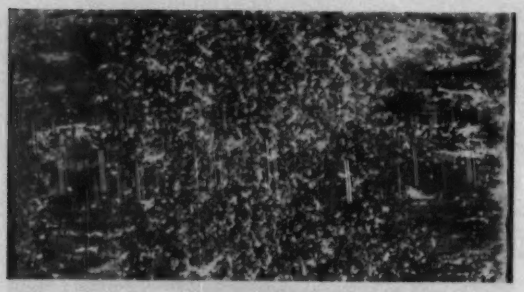


Fig. 7—Etched longitudinal section, showing ingot structure

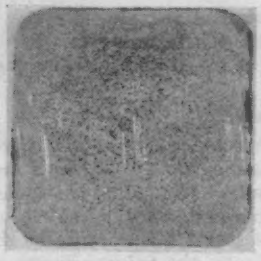


Fig. 8—Sulphur print of transverse section × ½

Macrostructure of the Ingot

Cross-sections of continuously cast ingots are similar to conventional ingots, consisting of a chill zone of fine equiaxed crystals followed by a zone of columnar crystals, the length of which depends upon the rate of cooling and the thermal characteristics of the alloy. The centre of the ingot is occupied by a zone of equiaxed dendrites accompanied by shrinkage porosity, the degree of the latter being controlled by the casting conditions.

A typical etched ingot section is shown in Fig. 7. Generally the degree of central unsoundness tends to increase with increase in the casting speed, but is generally reduced by the application of secondary cooling. An example is given by the two instances of silico-manganese steel shown in Table I; central looseness was less pronounced in the secondary-cooled ingot, even though it was cast at a much higher rate.

The depth of the chill zone depends upon the severity of the initial cooling imposed on the molten metal and on the degree of the superheat; to avoid ingot cracking and metal breakout, a sufficiently robust zone is required to withstand the ferrostatic pressure imposed upon the skin by the liquid interior when the ingot is withdrawn from the mould.

At the same time this chilled zone may have to withstand severe twisting stresses set up as a result of non-uniform cooling. Many ingots show a lack of symmetry, the square sections tending to approximate to a diamond shape; if this is severe, it may result in sub-surface cracks near the corner of the ingot. It has been found, however, that these cracks disappear on hot working, provided that they do not run out to the surface, where they may be oxidized on reheating and effectively prevented from welding.

The asymmetry of section is likely to cause more difficulty during subsequent working than the sub-surface cracks and demands great care in mould design and manufacture to ensure uniform heat transfer in the mould, and equal care in assuring uniform secondary cooling.

Sulphur prints of ingot cross-sections (Fig. 8) indicate that the chill zone contains slightly less sulphur than the rest of the section, but analysis shows that no gross segregation of sulphur, phosphorus or carbon takes place.

Sulphur prints of longitudinal sections (Fig. 9) show faint V segregates of sulphur occurring during the feeding of the liquid centre; they tend to be more pronounced at high speeds. This segregation is slight and rapidly disappears on hot working. It is interesting to note that at high speeds and with metals of wide freezing ranges, central porosity often takes place along the lines of the V segregates, but that given sufficient hot working (say 80% reduction in area) the porosity and segregation is removed.

The grain size of billets rolled from continuously cast ingots is not substantially different from conventional steel and responds to refinement by aluminium additions in much the same way. Because of the accessibility of the pouring system it is possible, in continuous casting, to make the aluminium addition to the mould in the form of a wire feed into the tundish stream, and so remove the pouring difficulties experienced with aluminium-treated melts.

Mechanical Properties

Numerous trials have shown that no difficulty is encountered in hot working without surface rectification, provided that casting conditions have limited the occurrence of surface defects as mentioned previously. Sections of continuously cast ingots 3 in. and 4 in. square have been upset-forged without splitting on the undressed faces, and these forgings

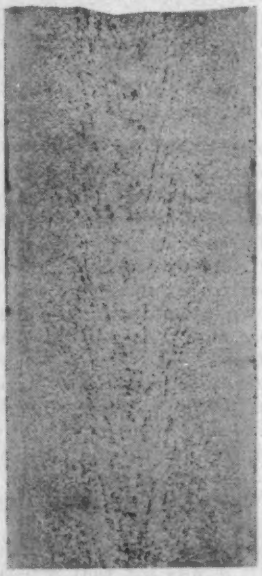


Fig. 9—Sulphur print of longitudinal section × ½

Fig. 10—Etched longitudinal section of portion of slab in planetary mill ' bite '

have been drop-forged into a variety of shapes with complete success. Several ingots of differing analyses have been rolled into billets and bars of varying size, and it was found that all the specified mechanical properties were passed, provided that a certain minimum reduction in area was accomplished in hot working. Whilst good results have been achieved with as little as 50% reduction in area in some instances, a safe minimum cannot be fixed below 85% in other more rigid specifications.

Table II gives examples of the mechanical properties obtained on two different steels cast continuously and then rolled into bars.

In addition to the tests made on square ingots, a slab ingot of 9 in. × 1¾ in. section and 20 ft long was rolled into 0·100 in. thick strip at one pass in a planetary mill, without any surface dressing other than descaling. Some of this strip was then successfully formed into a type of slotted angle, although the metal was of too high a carbon content for the intended produce. Test pieces cut from the hot-rolled strip showed uniform and satisfactory mechanical properties in both the longitudinal and transverse directions. Figure 10 is a section from the part of the slab left in the ' bite ' of the planetary mill.

One quality of steel was produced outside the B.S. 970 Specification: this was a file steel of 1·2% C. This alloy has a freezing range of about 260° C, and proved difficult to cast until the superheat was reduced to a minimum. Sections of this material were rolled and processed into finished files at the works of a member firm with great success, and the files compared favourably on efficiency tests with files cut from conventionally cast material.

Table II—MECHANICAL PROPERTIES OF CONTINUOUSLY CAST STEELS

	Brinell Hardness No.	Ultimate Tensile Strength, tons/in² (minimum)	Yield Stress, tons/in² (minimum)	Elongation, % (minimum)	Izod Impact Value, ft-lb (minimum)
En. 18 Steel: 1% Cr Steel for General-purpose Forgings					
B.S.970 Specification for ruling section 4in.	201–255	45	34	22	40
Recorded values	212–220	49	43	29	65–75
B.S.970 Specification for ruling section 2½in.	223–277	50	38	20	40
Recorded values	235–241	54	47·5	27	60–70
En. 5 Steel: " 30 " Carbon Steel for General Purposes					
B.S.970 Specification, normalized condition	143–193	32	16	25	20
Recorded values	160–180	37	24	35	30–40
B.S.970 Specification for ruling section ¾ in.	179–229	40	28	20	20
Recorded values	215–230	44	32	25	40–60

Non-metallic Inclusions

The system of metal feeding employs a longer refractory path than conventional top-pouring, but less than conventional bottom-pouring. Trials in which teeming into the tundish was interrupted to cast a small reference ingot without stopping the casting progress showed no significant difference in non-metallic inclusion levels between the continuous-cast ingot and the reference ingot, which was top-poured into a split chill mould.

The inclusions found are mostly mixed sulphides and silicates with trails of hercynite when aluminium has been used. Such inclusions have tended to concentrate to the longitudinal axis of the ingot, but consistently dispersed along the length of the ingot.

Although these results indicate that there is no increase in inclusions resulting from the tundish lining, the high preheat attained still makes it desirable to use a higher-quality refractory than conventional casting-pit bricks. By doing so, excessive wear of the lining is prevented and its life is prolonged. The cost will still be less *pro rata* than for conventional bottom-pouring practice.

SUMMARY AND CONCLUSIONS

A brief description has been given of the design and operation of the experimental continuous casting plant at the B.I.S.R.A. Laboratories in Sheffield, and in particular the principle of the spring-mounted mould has been discussed.

The plant has been largely used to provide sample casts for member firms, and a general account of the characteristics of the ingot has been given. The ingots are characterized by a very good surface and comparative freedom from segregation; a certain amount of central looseness may be present, depending on casting conditions, but in every case it has been eliminated satisfactorily on subsequent hot-working.

It should be remembered that the product is an ingot in structure, and must be hot-worked to give good mechanical properties; with some specifications, 50% reduction in area is adequate, whilst with more rigid specifications 85% reduction is necessary.

References

1. J. Savage and W. H. Pritchard: *J.I.S.I.*, 1954, vol. 178, pp. 269–277; J. Savage: *Metal Treatment*, 1955, vol. 22, pp. 277–287; D. M. Lewis and J. Savage: *Met. Rev.*, 1956, vol. 1, 65–116.
2. British Patent No. 715,282.
3. British Patent No. 743,349.

Summaries of Papers for Special Meeting in Belgium 1958

[Continued from page 112]

Continuous Casting on the B.I.S.R.A. Experimental Plant*

By G. Fenton and J. Pearson
(*British Iron and Steel Research Association*)

The design and operation of the B.I.S.R.A. experimental continuous-casting plant and the principle of the spring-mounted mould are described. The product of the plant has been sample casts for assessment of external and internal quality and workability. The ingots are characterized by good surface and comparative freedom from segregation; central looseness is sometimes present, depending upon casting conditions, but in every case it has been eliminated on hot-working. Because the product has a cast structure it requires hot working to give satisfactory mechanical properties; the amount of reduction in cross-sectional area to achieve these varies from 50% to 85%.

Control of the Supply of Molten Metal for Continuous Casting

By W. Siegfried
(*Battelle Memorial Institute, Geneva*)

This paper describes an electromagnetic method of controlling the supply of liquid steel in a continuous-casting installation consisting of a rolling mill, itself designed for the manufacture of welding rod. After a brief reference to magnetic pumps now on the market—with the pump directly connected to the electricity supply, or working with an induced electric current—the author describes the principle of the installation put into service by the Battelle Institute, Geneva. He then reviews some technical problems: choice of materials, cooling of the iron of the magnet and coils without over cooling the steel itself, and the arrangement of the magnetic circuit.

10th Session:

"INDUSTRIAL APPLICATIONS OF CONTINUOUS CASTING"

Some Features of Continuous Casting at Barrow

By I. M. D. Halliday
(*Barrow Steel Works Ltd.*)

The high-speed works process developed at Barrow on a 5-ton (later 8-ton) capacity pilot plant is described. Plain carbon and low-alloy steels are regularly cast into 2–4-in. square billets and 6 in. × 2 in. slabs. The use of preheated ladles to transfer and hold liquid metal, features of mould design and operation including special reciprocation arrangements and flexing action, the preferred character of the cooling sprays below the mould, and the structure of the product are outlined. Bending rolls to facilitate horizontal discharge and automatic mould metal-level control have also been developed.

Experience with the Continuous Casting of Steel in Western Germany

By K. G. Speith and A. Bungeroth
(*Duisburg–Huckingen*)

After a historical review of continuous casting in Germany, the authors examine several fundamental aspects of this technique. First, they discuss the casting rate of killed and rimming steels of different types: open-hearth, electric, and basic Bessemer. They also discuss the rate of extraction and solidification of ingots. They compare types of ladle and discuss the use of an intermediate receptacle to control the supply or to distribute the steel to the various lines of the plant. They proceed to examine problems relating to the ingot mould and its method of suspension. The paper concludes with a study of methods of increasing the casting rate, and of constructional characteristics.

Recent Experience in the Continuous Casting of Steel

By H. Krainer and B. Tarman
(*Gebr. Böhler A.G.*)

The paper first deals with continuous casting in Austria and briefly outlines the installations of Gebr. Böhler A.G. of Kapfenberg and those of Eisenwerk Breitenfeld GMBH of Wartberg. The former plant casts products from 100 to 600 kg/m and the latter up to 150 kg/m. The authors then treat the Kapfenberg plant in detail. They describe the construction of the ingot mould, its life, and the cooling through the walls. An important section is devoted to the conditions of cooling of the metal in the special cases of rectangular sections. Three methods have been used for this study: cutting the bar near the lower end of the cone of solidification, tracer studies with radioactive phosphorus or sulphur, and the addition of lead. The authors next give an indication of the rates of casting of slabs and show the need for installing several lines to reach higher tonnages.

The final part of the paper is devoted to consideration of defects: external cracks due to irregular thicknesses in the crust of solidified metal in the mould or as much to reheating of the surface in the mould as to subsequent cooling; internal fissures in certain steels with a high $\gamma \rightarrow \alpha$ transformation point and a high rate of transformation in the pearlitic zone; and internal cracks due to the influences of high mechanical forces.

Continuous Casting of Steel in France

By P. Thomas
(*Société des Hauts Fourneaux et Forges d'Allevard*)

The paper describes continuous casting in France by surveying the three existing plants.

The Jacob Holtzer plant at Unieux, the oldest, aims at the production of steel billets of rather small sizes (40–80 cm²) of spring steels and at low speeds. At each operation 1·5 tons of steel billets are cast.

The works of the Éts. Cail at Denain, where 85,000 tons were cast by the end of October in less than three months, the aim is to make steel billets, standard and special, of about 600 cm² section at low speeds (of the order of 0·5 m) but at high total rates (35–60 tons/h). The plant permits the casting of 35-ton ladles in 45 min in four moulds of 240 × 240 mm and 1 m high. Various types of steels have been cast: extra-mild killed or unkilled steels, semi-hard and hard carbon steels, Cr–Ni–Mo steels, and in particular silicon steels for magnetic sheet.

The third plant, that at Allevard, aims at the production, at a high rate (3–6 m/min) and medium output of 10–12 tons/h, of billets in standard or alloy steels, especially spring steels and of small sizes (50–110 cm²). This involves casting a ladle of 12 tons in 50–70 min, according to the profile of the billet (75 mm × 75 mm, 140 mm × 90 mm). The paper finally describes the plant, with attention to the questions of quality, the economic aspects, and plans for a new installation.

Continuous Casting at Atlas Steels Ltd., Welland, Ontario, Canada*

By G. C. Olson

The paper begins with an account of the factors influencing the decision of Atlas Steels Ltd. to install a continuous-casting plant. The installation and operation of the Rossi-Junghans machine are fully described. The machine is supplied with steel from arc furnaces and cast from bottom-pour ladles. The present production programme covers slabs and billets in austenitic stainless steel, tool-steel billets, and billets for seamless pipe.

Next, the paper gives details of some of the many development problems that have been encountered and overcome; these include temperature control, melting techniques, ladle and tundish design, protective atmospheres, and cooling and casting speeds. There is a final section on the economics of continuous casting.

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Special Meeting in Belgium and Luxembourg

The Institute is holding a Special Meeting in Belgium and Luxembourg from **18th to 28th June,** at the invitation of the Centre National de Recherches Métallurgiques, the Groupement des Industries Sidérurgiques Luxembourgeoises, and the Groupement des Hauts Fourneaux et Aciéries Belges. The meeting is being held in conjunction with the Journées Internationales de Sidérurgie, which are being organized on the occasion of the Brussels World Exhibition.

The full programme of the meeting was published in the May issue of the *Journal* (pp. 12–14). Summaries of the papers to be presented and discussed at the Technical Sessions appear on pp. 109–112 and 168 of this issue.

It was announced at the Annual General Meeting on 7th May that the Patrons of the Meeting in Belgium and Luxembourg, H.M. King Baudouin, King of the Belgians, and H.R.H. Charlotte, Grand Duchess of Luxembourg, had graciously accepted Honorary Membership of The Iron and Steel Institute.

Changes on Council

At the Council meeting on 7th May, the following elections were made:

Vice-President Mr. D. A. OLIVER, C.B.E., M.SC., F.INST.P., F.I.M. (B.S.A. Group Research Centre).

Member of Council Mr. R. F. SUMMERS (John Summers and Sons, Ltd.).

The Council has decided to co-opt Additional Honorary Members of Council up to a maximum of six, in order to provide better representation of certain classes of member. They will normally serve for three years and not be eligible for re-election without a break of one year, save in exceptional cases. At the meeting on 7th May, the following Additional Honorary Members of Council were elected:

Mr. R. W. EVANS, T.D., M.MET., M.INST.P., F.I.M. (Steel Company of Wales Ltd.)

Dr. L. NORTHCOTT, F.R.I.C., F.I.M. (Armament Research and Development Establishment).

NEWS OF MEMBERS

Mr. **G. L. Bailey,** C.B.E., has been elected a Vice-President of The Institute of Metals.

Dr. **W. D. Biggs** has left Murex Welding Processes Ltd., to become University Lecturer in Engineering at Cambridge.

Dr. **Maurice Cook** has been elected Vice-President of the Aluminium Development Association for 1958–1959.

Mr. **P. M. Cook** has resigned his post as Head of the Rolling Section of the B.I.S.R.A. Mechanical Working Division to become Research Manager with J. J. Habershon and Sons, Ltd.

Mr. **V. P. Delport** has been awarded a Meritorious Services Medal for 1958 by the Institute of British Foundrymen.

Mr. **D. Hall** is now General Works Manager of Low Moor Alloy Steelworks Ltd. and Yorkshire Rolling Mills Ltd.

Mr. **M. M. Hallett** has been awarded the Oliver Stubbs Medal for 1958 by the Institute of British Foundrymen.

Mr. **J. A. Hoskins** has been awarded the degree of Ph.D. by Sheffield University, and is now Chief Metallurgist to Qualcast Ltd.

Dr. **L. B. Hunt** has been elected a Member of Council of The Institute of Metals.

Dr. **N. P. Inglis** is now Chairman of the Executive Committee of the Aluminium Development Association.

Lord **Kirkwood of Bearsden** has been elected a Member of Council of The Institute of Metals.

Mr. **F. Moore** has been appointed Deputy Chief Engineer of Steel, Peech and Tozer.

Professor **A. G. Quarrell** is Pro-Chancellor of the University of Sheffield for 1958–1959.

Mr. **W. F. Randall** has been elected a Member of Council of The Institute of Metals.

Mr. **P. A. Russell** has been awarded the E. J. Fox Medal for 1958 by the Institute of British Foundrymen.

Mr. **J. D. Salmon** has been appointed Assistant Manager of the Rotherfield Works of Samuel Fox and Co., Ltd.

Mr. **D. R. Scarrott** is now Technical Assistant to the Manager of the Cold Rolled Strip Department of Samuel Fox and Co., Ltd.

Mr. **S. Selmer-Olsen** has emigrated from Norway to the Union of South Africa.

Mr. **H. L. Trafford** has been elected Chairman of the North Western Section of the Institute of Fuel.

Mr. **C. H. Wilson** is Senior Vice-President of the Institute of British Foundrymen for 1958–1959.

Obituary

Mr. **David K. Barclay** (*elected* 1938), of Redcar, on 28th January, 1958.

IRON AND STEEL ENGINEERS GROUP

Engineering Committee

Mr. W. M. Larke has relinquished the chairmanship of the Engineering Committee, but has agreed to remain on the Committee for a year. He is succeeded by Mr. F. B. George (Consett Iron Co., Ltd.). Sir Henry Clay, BT., Mr. W. A. J. Dinwoodie, Mr. C. E. H. Morris, Mr. D. E. Moxey, and Mr. C. M. Slocombe have resigned, having completed three years' service; their places are being taken by Mr. W. S. Atkins, Mr. H. Darnall, Mr. R. M. L. Elkan, Mr. R. Stewartson, and Mr. N. T. Williams.

AFFILIATED LOCAL SOCIETIES

Liverpool Metallurgical Society

The following officers and committee were elected for the 1958–1959 session at the 10th Annual General Meeting of the Liverpool Metallurgical Society:

President

C. Bodsworth, PH.D., M.MET., A.I.M.

Senior Vice-President B. Ryan — *Vice-President* R. Cobill

Retiring President
J. S. W. Graham, M.ENG., A.M.I.E.E.

Honorary Secretary J. F. Giblin, B.ENG., A.I.M. — *Honorary Treasurer* B. Todd, M.ENG.

Members of Committee
W. J. Bannister, B.SC.; E. A. Jenks; F. R. Brace; Professor W. S. Owen, PH.D., M.ENG., F.I.M.; G. T. Callis, B.SC. (TECH.), F.I.M.; W. Rose, J.P.

Honorary Vice-Presidents
R. S. Brown, M.B.E., A.M.C.T., F.I.M.; V. L. Farthing, M.I.MECH.E., M.I.MAR.E., M.INST.PET.; H. Edwards, F.R.I.C., F.I.M.; S. J. Kennett, PH.D., B.SC., A.R.S.M., F.I.M.

CONTRIBUTORS TO THE JOURNAL

J. T. Maskrey, B.SC.—Metallurgy Division, Atomic Energy Research Establishment, Harwell.

Mr. Maskrey was born in 1931 and educated at Wirksworth Grammar School. He joined the A.E.R.E. Metallurgy Division on leaving school in 1948; as a result of part-time study at the Oxford School of Technology, he later obtained an external B.Sc. degree of London University. His work at the A.E.R.E. has included the study of various alloy systems of uranium and research into liquid-metal problems associated with liquid-metal fuel reactors. Mr. Maskrey is at present a member of a team engaged in the study of metals for use in the controlled thermonuclear reactor.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Staff Changes

Mr. S. S. Carlisle, M.SC., A.M.I.E.E., Head of the B.I.S.R.A. South Wales Laboratories since 1954, has been appointed Head of the Association's Physics Department at the Battersea Laboratories, from 1st July. In addition he will continue to have an executive responsibility for the South Wales Laboratory as Deputy Head of the Mechanical Working Division (Swansea).

Mr. Carlisle is a graduate of Queen's University, Belfast (College of Technology). He joined B.I.S.R.A. in 1946 after four years with the staff of the Director of Scientific Research, Admiralty, when he was engaged on the development of radar and gun control equipment. He became Head of the Instrument Section of the Physics Department in 1947, and was particularly concerned with development of measuring and control systems for furnaces, hot-strip width measuring techniques, and automatic strip gauge control systems.

His successor at Sketty Hall will be Mr. W. N. Jenkins, B.SC., A.M.I.E.E., at present with the Plant Engineering Division at Battersea. A graduate of University College, Swansea, Mr. Jenkins joined the British Thomson Houston Co., Ltd., Rugby, after service in the R.A.F. He then joined McLellan and Partners, where he began his connection with the steel industry. Since 1952 Mr. Jenkins has been with B.I.S.R.A., engaged in various projects connected with tandem rolling, automatic control, translator devices, and programming.

INSTITUTE OF METALS

Medallists of 1958

The Institute of Metals Medal in Platinum for 1958 has been awarded to Professor Emeritus R. S. Hutton, M.A., D.SC., in recognition of his outstanding work in connection with the science and practice of non-ferrous metallurgy.

The *Rosenhain Medal* for 1958 goes to Dr. J. H. Hollomon (General Electric Company Research Laboratory, U.S.A.), in recognition of his outstanding contributions to knowledge in the field of physical metallurgy.

POWDER METALLURGY JOINT GROUP

Forthcoming Meeting

The next meeting of the Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals is to be held at Church House, Great Smith Street, London S.W.1., on Tuesday and Wednesday, **16th and 17th December.** It will consist of a symposium on "The Powder Metallurgy of Ceramic-Metal Materials"; there will be an introductory lecture on the evening of the Tuesday, and the whole of the following day will be devoted to the symposium itself.

EDUCATION

Conference on Precipitation Processes

A conference on "Precipitation Processes in Steels" has been arranged by the Department of Metallurgy, University of Sheffield, and will take place in St. George's Square, Sheffield, 1, between Wednesday, 2nd July, and Friday, 4th July.

There will be four main sessions: 1. precipitation in ferritic steels; 2. precipitation in austenitic steels; 3. intergranular fracture in steels; and 4. precipitation during creep.

Accommodation for participants in the Conference has been arranged in Stephenson Hall, University of Sheffield. Attendance at the meetings will be limited and early applications are advised. There will be a registration fee of £2 0*s.* 0*d.*, which will cover the cost of preprints of a number of the papers to be presented, and of light refreshments during the sessions.

Application forms and further information can be obtained from: The Professor of Metallurgy, University of Sheffield, St. George's Square, Sheffield, 1.

School of Welding Technology

The Institute of Welding has organized a School of Welding Technology, offering intensive full-time courses in the field of welding and fabrication. The first series of courses, between October, 1957 and March, 1958, was very well received, and the second session is now in progress.

Day courses in inert-gas welding, the control of distortion, and residual stress and stress relief are offered in the second session; future courses include design and construction of welded storage tanks, metal spraying, welding of atomic plant, etc. Prospectuses and application forms may be obtained from the Secretary, The Institute of Welding, 54 Princes Gate, London S.W.7.

Summer School on Non-destructive Testing

A summer school on the principles and practice of non-destructive testing, intended to benefit senior and chief inspectors from industry, is to be held at the Manchester College of Science and Technology on 8th–12th September. This summer school has been sponsored by the British National Committee for Non-destructive Testing, of which The Iron and Steel Institute is a mem-

ber, and is being organized by the Manchester College of Science and Technology, the Manchester Association of Engineers, and the Institution of Engineering Inspection.

Those attending the course are expected to have some basic knowledge of non-destructive testing techniques. The physical background of the subject and the interpretation of test results will be the dominant themes of the course. The total cost of the course is expected to be approximately £18. Accommodation for those attending will be provided in the residential quarters of Hulme Hall. For further details, please apply to the Organising Lecturer, Dr. J. H. Lamble, PH.D., D.SC., M.ENG., M.I.MECH.E., Manchester College of Science and Technology, Manchester 1.

Metallurgical Technicians

The City and Guilds of London Institute is exploring the need for a course designed for what have been described as " metallurgical technicians ". It has been suggested that there is a gap between the Institute's Operative courses on the one hand and the Ordinary National Certificate in metallurgy on the other. Investigations are in the hands of the Institute's General Advisory Committee for Metallurgical Subjects.

Financing of Sandwich Courses

In statements issued recently, the Ministry of Education and the Federation of British Industries urged that firms sending employees on advanced sandwich courses should pay their fees and salaries during the course where possible; in cases where firms were unable to do so, local authorities should give sympathetic consideration to applications for aid.

NEWS OF SCIENCE AND INDUSTRY

Galvanizing Line at Ebbw Vale

The new Armco–Sendzimir continuous galvanizing line installed at the Ebbw Vale works of Richard Thomas and Baldwins Ltd. is now in production. It is designed for an output of either galvanized sheet or coil at a rate of 10 tons/h and can handle steel strip up to 48 in. wide.

Cold-reduced coils are taken by roller conveyor through the stages of cleaning, heat-treatment, pickling, coating, shearing to size, and inspection on a single continuous operation. This represents a radical departure from earlier methods of sheet galvanizing, and gives metal fabricators a steel sheet with a coating adherent enough to withstand drawing and forming operations, up to the limit of the steel base, without peeling or flaking. The line, nearly 700 ft long, 36 ft wide, and 30 ft high, is the first of this size to be installed in the U.K.; it should be an important factor in meeting the keen competition for the sale of galvanized sheet in world markets.

Apart from the electrical and mechanical maintenance staffs, only six men are required per shift to control the equipment. The line operates under licence from the Armco Steel Corporation of the U.S.A.; the Head Wrightson Machine Co., Ltd., and Birlec Ltd. were the main contractors.

New Slabbing Mill for Appleby-Frodingham

The Appleby-Frodingham Steel Company have ordered from Davy and United Engineering Co., Ltd., a new slabbing mill, to cost over £500,000. The mill is expected to come into operation towards the end of 1959.

The existing Davy 42-in. slabbing mill has been the primary rolling unit in the Appleby-Frodingham plate mills since 1926. Although still capable of meeting present requirements, the manipulators in particular are not to the standard necessary to deal with the higher output which will be required from the mill when the company's plate-mill modernization scheme is completed next year.

The new 45-in. mill will be equipped with universal manipulators; the associated roller tables are included in the order. It will be driven by the original 6000-h.p. electric motor through the existing pinion stand. Designed to handle 15-ton ingots, the mill will have an initial weekly production target of about 17,000 tons, but this may be stepped up to 25,000 tons in due course.

Induction Heating Plant for Roll Hardening

Birlec Ltd. have built and installed at the Glasgow works of William Beardmore and Co., Ltd., an induction heating equipment for hardening steel rolls; the new equipment has been developed jointly by the two companies. It is designed to deal with rolls up to 18 ft long and 32 in. dia.

The work is supported vertically between centres, the lower being motor-driven, so as to rotate the roll slowly during hardening. Heating is by high-frequency eddy currents, induced by a water-cooled coil. Temperature control is by radiation pyrometer. A water manifold on the heating head permits the roll surface to be quenched.

Normal operating procedure involves preheating at low power, followed by a single hardening pass. Traversing speed and power level during hardening can be adjusted to produce the requisite depth of hardness. A large roll can be preheated and hardened in about an hour.

Sixth Gillett Lecture

The 6th Gillett Memorial Lecture is being delivered at the 61st Annual Meeting of the American Society for Testing Materials in Boston, Mass., on 24th June, by Dr. Clyde Williams. He has chosen as his subject " High-temperature Metals—Their role in the Technological Future."

Industrial Safety Award

The Sir George Earle Trophy for a notable achievement in the cause of accident prevention has been awarded for 1958 to Imperial Chemical Industries Ltd.

Straining Frame to Test Structural Materials

Under the direction of Professor W. Fisher Cassie, PH.D., M.S., F.R.S.E., the Workshop Staff of the Civil Engineering Department at King's College, University of Durham, have constructed a heavy straining frame for the testing of structural materials, which include reinforced beams. The heavy rolled-steel joists used in the construction of the frame were 20 in. × 7½ in. with corner stiffeners and gussets to take the concentration of stress at that point. The use of heavy sections caused the welded joints to be subjected to a considerable degree of restraint, and for this reason, Ferron (New Type) electrodes, supplied by Quasi-Arc Ltd., were used. These electrodes are particularly suitable for producing sound welds under conditions of restraint.

Acoustic Laboratory

An acoustic laboratory for research into the suppression of noise in industrial fans and blowers was recently put into service at the Tottenham works of Keith Blackman Ltd., London. The sound-proof test chamber is ventilated to dissipate heat generated from any unit under test up to a limit of 25 b.h.p., and laboratory equipment includes automatic instruments to record sound frequency analysis as well as portable units to measure sound levels and air volume and pressure. It is hoped that data and testing procedures developed in this and other laboratories in the U.K. may lead to a British Standard on noise levels in fan engineering equipment

B.I.S.F. Annual Report

The Annual Report of the British Iron and Steel Federation for 1957, which appeared recently, shows that U.K. steel output continued to advance at a time when in other countries, such as the U.S.A., it had ceased to rise or was declining. The U.K. rate of increase dropped in the last quarter of the year from 6% to 5%. Home consumption was in general lower than in 1956, and imports of steel were also reduced by over 7,000,000 ingot tons; the reduction might have been still greater but for some long-term contracts.

During the year some 350 new or replacement coke-ovens came into operation, and about a million tons of additional sintering capacity were installed. New blast-furnaces were blown in in Scotland and N.E. England, and additional open-hearth furnaces started up in Scotland, South Wales, Cheshire, Lancashire, and Sheffield. Additional rolling-mill capacity came into operation at Sheffield and in the North-East. Taking into account these and other projects likely to reach completion during the year, capacity in 1958 should be 16 million tons of pig iron and over 23 million ingot tons of steel.

Copies of the report are available from the Federation, Steel House, Tothill Street, London S.W.1.

Sinter Plant for Workington

The existing sinter plant and fine-ore stockyard at the Workington Iron and Steel Company is to be replaced. The new plant, which will be ready in 2½ years' time, is estimated to cost about £2,500,000.

It is anticipated that the new single-strand continuous plant, which is being supplied by Head Wrightson and Co., Ltd., will produce 12,500 tons of self-fluxing sinter per week. The stock bays will have a capacity of about 40,000 tons of ore fines. The sinter machine will be 72 in. wide and is to have an effective length of 168 ft over 28 windboxes.

Industrial Publications Received

Brochure no. 579 of the Visco Engineering Co., Ltd., deals with "Visco Water Coolers"; this supersedes their earlier brochure no. 514.

Holmes Conversville Positive Blowers Type RB are the subject of publication no. 71 from W. C. Holmes and Co., Ltd. Their publications nos. 69 and 72 have also been received; their subjects are respectively Holmes Elex electrical precipitators and a general survey of other dust collection and control equipment manufactured by the company.

British Ropes Ltd., have recently issued a booklet on "Superloop."

"Sillmax" bricks are described in a recent publication (no. 82) from General Refractories Ltd.

The wide range of ferro-alloys marketed by Union Carbide Ltd., Alloys Division, are described in a new publication, "Product Sketches."

Brochure no. 358 from Refractory Mouldings and Castings Ltd., is entitled "Refractory Shapes."

A leaflet from Ashmore, Benson, Pease and Company describes their slag notch stopper (Bailey design).

Bulletin M.2B of Metalectric Furnaces Ltd. deals with vertical air-circulation furnaces.

Sunvic Controls Ltd. have recently issued the following technical publications: No. 1201 "Liquid Level Transmitter"; No. 1682 "Multi-Function Relays"; No. 1761 "Pneumatic Multiplying Relays"; No. 2011 "Energy Regulators"; No. 2121 "Electronic Proportional Resistance-Thermometer Controller".

A new catalogue of air gauges has been published by Teddington Industrial Equipment Ltd.

Corrigendum

In the paper "The Driving Rate of Open-hearth Furnaces" by R. W. Evans et al. (*J.I.S.I.*, 1958, May, vol. 189, pp. 19–28), the degree "B.Sc.(Tech.)" was omitted from the name of Mr. J. F. Allen, one of the co-authors.

DIARY

18th–28th June—Chemical and Petroleum Engineering Exhibition—Olympia, London.

18th–20th June—Société Française de Métallurgie and Institute of Physics—Joint Meeting on Non-destructive Testing—Paris.

18th–28th June—The Iron and Steel Institute—Special Meeting in Belgium and Luxembourg.

22nd–27th June—Fifth International Galvanizing Conference—Scheveningen and Knokke-le-Zoute, Belgium.

23rd–28th June—Third International Coal Preparation Congress—Brussels and Liège.

CO-OPERATIVE TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 76 of the May, 1958, issue of the Journal:

723. Schrader *et al.*: "Studies of the Structure of Steels with High Contents of Carbide-forming Alloying Elements." *Arch. Eisenhüttenwesen*, 1957, Aug., pp. 461–468. (£4 15*s*. 0*d*.)

729. Belous: "Welding of Gears under Protection of Carbon Dioxide." *Svarochnoye Proizvodstvo*, 1956, No. 3, pp. 20–22. (£1 15*s*. 0*d*.)

743. Antropova *et al.*: "Influence of Deoxidation with Aluminium on the Quality of Structural Steel." *Stal*, 1957, Jan., pp. 64–69. (£4 0*s*. 0*d*.)

749. Weyel and Weide: "The New Light Section and Wire Rod Mill of the Klöckner-Hüttenwerk Haspe in Hagen-Haspe." *Stahl u. Eisen*, 1957, Oct. 17th, pp. 1464–1476. (£6 10*s*. 0*d*.)

761. Kharash *et al.*: "Problems in Sinter Production." (Including a Description of a 2000 sq. ft. machine). *Stal*, 1957, Feb., pp. 106–114. (Abridged). (£6 0*s*. 0*d*.)

816. Eggers: "The Mottling of Tinplate." *Arch. Eisenhüttenwesen*, 1957, Dec., pp. 777–783. (£3 5*s*. 0*d*.)

825. Piguzov: "Study of Internal Friction in Alpha and Gamma Phases of High-chromium Steel." *Dok. Akad. Nauk S.S.S.R.*, 1957, vol. 112, No. 4, pp. 636–639. (£3 0*s*. 0*d*.)

856. Kalan: "Die Making by Means of Hot Pressing." *Kohászati Lapok*, 1954, Sept., pp. 390–399. (£3 10*s*. 0*d*.)

874. Haller: "How to determine Forging and Finishing Periods." *Werkstatt u. Betrieb*, 1957, Apr., pp. 227–232. (£5 0*s*. 0*d*.)

875. Göschel: "Correct Gating Technique for Medium-sized and Large Castings." *Giessereitechnik*, 1957, July, pp. 160–162. (£3 0*s*. 0*d*.)

898. Khlebnikov *et al.*: "Rational Rail-pass Design." *Stal*, 1957, Dec., pp. 1103–1107. (£3 0*s*. 0*d*.)

914. Weber: "The Use of Fuel-oil in Forges." *Stahl u. Eisen*, 1958, Jan. 23rd, pp. 87–92. (£4 5*s*. 0*d*.)

915. Vom Ende and Mahn: "Operational Results when Blowing Basic Bessemer Melts Using the IRSID Opacimeter." *Stahl u. Eisen*, 1958, Apr. 3rd, pp. 412–418. (£5 10*s*. 0*d*.)

932. Lozinskii: "A Method of Determining the Variation of Hardness of Alpha and Gamma Iron Heated up to 1100° C *in vacuo*." *Dok. Akad. Nauk S.S.S.R.*, 1952, vol. 84, No. 1, pp. 63–66. (£2 10*s*. 0*d*.)

933. Lozinskii and Guterman: "Indentors of High Heat Resistance for Hardness Tests on Metals up to 1300° C *in vacuo*." *Zavods Lab.*, 1956, vol. 22, No. 11, pp. 1358–1363. (£3 0*s* 0*d*.)

934. Gubin: "Pelletising Finely Pulverised Iron Ores." *Metallurg*, 1958, No. 2, pp. 3–4. (£1 10*s*. 0*d*.)

935. Hori: "A study on Castability (10th Report). On the Effects of Heating Velocity of Melting on Runnability." *Nippon Kinzoku Gakkai-Si*, 1954, Sept., pp. 549–551. (£4 0*s*. 0*d*.)

952. Piotrkovskii and Ashikhmin: "Automatic Regulation of Blast Furnace Working." *Stal*, 1957, No. 1, pp. 16–20. (£3 10*s*. 0*d*.)

953. "Bibliography of Work by the Max-Planck Institute for Work Physiology in Dortmund." June 1956, June 1957. (£4 0*s*. 0*d*.)

954. Astrand: "Physiological Viewpoints on Working Positions and Work Kinetics." *Jernkont. Ann.*, 1955, vol. 139, No. 10, pp. 817–828. (£3 10*s*. 0*d*.)

955. Ahlegren: "Backache—Preventative Measures—Working Positions." *Jernkont. Ann.*, 1955, vol. 139, No. 10, pp. 829–846. (£4 10*s*. 0*d*.)

956. Sebardt: "Biotechnology—a Neglected Production Factor." *Jernkont. Ann.*, 1955, vol. 139, No. 10, pp. 805–816. (£3 0*s*. 0*d*.)

958. Breckpot and Juchniewicz: "Spectral Control of Oxygen-steam Blown Heats." (Paper presented to the 27th Congress of Industrial Chemistry, Brussels, 1954.) (£2 0*s*. 0*d*.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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* Indicates that a translation is available.

ORES—MINING AND TREATMENT

The Caland Project at Steep Rock Lake. P. D. Pearson. (*Eng. J.*, 1957, **40**, Nov., 1657–1664). An account of the plans for iron ore production.

Typical Low Grade Iron Formations of Michigan. F. J. Tolonen, N. H. Manderfield and P. Jasberg. (*Min. Eng.*, 1957, **9**, Nov., 1256–1261).

Soviet Ore Resources: Enormous Production Potential East of the Caspian. R. Sewell. (*Iron Steel*, 1957, **30**, Dec., 652). Very large iron ore reserves, exceeding those of Lake Superior, have recently been discovered in the Kustanai basin in Russia. An outline is given of the development plans.—G. F.

Mining and Milling Methods and Costs, Ozark Ore Co., Iron Mountain Iron-Ore Mine, St. Francois County, Mo. R. F. Pettit jun., W. A. Calhoun and B. M. Reynolds. (*U.S. Bur. Mines Inf. Circ.*, 7807, 1957, Oct., pp. 46).

Narvick Handling Installation. E. Kemna. (*Demag News*, 1956, (146), 1–18). A full account of the iron ore handling system with coloured illustrations is presented.

The Development of Iron Ore Imports. T. B. Roddy. (*Steel Rev.*, 1958, Jan., 16–24).

BISC (Ore) Ltd. D. H. Kyle. (*Steel Rev.*, 1958, Jan., 24–33). An account of the origin and operation of the central ore importing agency.

M.V. Oredian. M. Goodwin. (*Steel Rev.*, 1958, Jan., 34–38). An account of the ore carrier and a voyage on her.

Flotation: The Art of Utilizing Modifying Agents. S. P. Moyer. (*Min. Mag.*, 1958, **98**, Jan., 9–16). Examples are mainly non-ferrous but include pyrites.

Agglomeration Flotation of Manganese Ore. E. H. Gates. (*Min. Eng.*, 1957, **9**, Dec., 1368–1376).

Correlation of Contact Angles, Adsorption Density, Zeta Potentials, and Flotation Rate. D. W. Fuerstenau. (*Min. Eng.*, 1957, **9**, Dec., 1365–1367).

Researches on the Magnetic Properties of Titaniferous Iron Sands in Hokkaido. K. Hirakoso. (*Tetsu to Hagane*, 1955, **41**, Sept., 1001–1002). [In Japanese].—K. E. J.

Dissolution of Pyrite Ores in Acid Chlorine Solutions. M. I. Sherman and J. D. H. Strickland. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 1, 1386–1388). The authors describe an apparatus and technique for reacting a known area of sulphide ore with a known volume of chlorine water, and measuring the rate of dissolution of the ore. Under all conditions studied, pyrite produces only ferric ions and sulphate ions, and the reaction is diffusion-controlled with an activation energy of about 5000 cal./mol.—G. F.

Grinding Magnetic Taconite in Rod Mills. E. M. Furness and A. S. Henderson. (*Min. Eng.*, 1957, **9**, Dec., 1359–1360). Studies on grinding led to the use of longer slow-speed ball mills.

Dearsenification of Limonite by Roasting. S. Sato. (*Tetsu to Hagane*, 1955, **41**, Sept., 936–939). [In Japanese]. A thermal analysis curve for scolodite ($FeAsO_4 . 2H_2O$) is presented, and the influences of temperature and of CO, CO_2 and nitrogen contents in various atmospheres on the dearsenification ratio are traced.—K. E. J.

New Ore Handling, Screening and Sintering Facilities at Sparrows Point. M. Becker and E. C. Olson. (*Iron Steel Eng.*, 1957, **34**, Nov., 96–108). Details are first given of the engineering and mechanical features of the new ore handling system at Sparrows Point. The eight possible modes of operation of the plant are outlined, and some of the design problems encountered are discussed. The electrical features are also described, many practical and tested ideas being incorporated to make the system a complete and integrated unit.—G. F.

New Process Developed for Treating Iron Ore Concentrates. (*Blast Furn. Steel Plant*, 1957, **45**, Dec., 1430–1431). A short illustrated account is given of a new process developed by Allis-Chalmers for pelletizing and heat treating magnetite concentrates.—B. G. B.

On the Standard Reducibility Test of Iron Ores by Hydrogen. K. Kanbara. (*Tetsu to Hagane*, 1955, **41**, Sept., 1002–1004). [*In Japanese*]. The apparatus is described, and degree of reduction against hydrogen flow is plotted for times of 10, 20, 30, 60 and 120 min with Vancouver ore. Results are given for reduction of various limonites, hematites, magnetites and sinter at 900° C.—K. E. J.

Solid State Diffusion in the Reduction of Hematite. J. O. Edström. (*Jernkont. Ann.*, 1957, **141**, (12), 809–836). [In English]. Reduction to magnetite and wüstite was studied between 600–1200° C using plates cut from single crystals and pressed between iron powder and wüstite powder in a neutral atmosphere. Rate constants were found close to those measured for the formation of magnetite by oxidation of wüstite and of wüstite from iron, and those for reduction of Fe_2O_3 in a gaseous atmosphere at 1000° were close to that expected for a solid state reaction. Self-diffusion constants were calculated and an approximate relationship to the rate constant is given. (78 references).

Mineralogical Composition of Self-Fluxing Sinters. N. G. Moleva and P. S. Kusakin. (*Stal'*, 1957, (12), 1068–1071). A study of limestone sinters showed that the phase composition depends largely on the amount of SiO_2. With 12–16% SiO_2, Fe–Ca and Al–Ca silicates are formed. Ca ferrites occur near the pores with 10–15%, and with ~ 7% the low-melting calcium-rich phase dissolves magnetite and, on cooling ferrites of constant composition separate. The particles remaining of the grains of dissolving magnetite nucleate the monocalcium ferrite formed. These may reach 30–45%. The higher-melting phase is a ferriginous glass. Limestone sinters are not strong. Micro-cracks pass through the cementing phase and seem to be due to rapid cooling. Slower cooling might increase the strength.

The Effect of Firing Temperature and Some Additions on the Strength of Iron Ore Pellets. C. Yoshii. (*Tetsu to Hagane*, 1955, **41**, Sept., 931–933). [In Japanese]. Results are reported for the apparent density and crushing strength of pellets, fired between 1100° and 1300° C, prepared from magnetite, limonite and limonite with added coke, bentonite or lime. The best strength was found with magnetite followed by limonite with 2% lime.—K. E. J.

[**Measurement of Wind-Box Temperature in Control of Pallet speed of the Dwight-Lloyd Sinter Machine.**] T. Saito. (*Tetsu to Hagane*, 1955, **41**, Sept. 934–936). [In Japanese]. Analyses are given of the temperatures in Nos. 10 and 12 wind-boxes for various sintering speeds and conditions.—K. E. J.

Studies on the Sintering Mechanism of Iron Ore Pellets. I. N. Nakamura and Y. Sato. (*Tetsu to Hagane*, 1957, June, **43**, 619–623).

[In Japanese]. Sintered pellets which had contained some carbon in the mix contained angular hematite crystals caused by grain growth of magnetite at an early stage of roasting; those heated in a furnace having a combustion chamber showed a network of hematite crystals. The dark blue colour of roasted pellets is caused by dissociation of ferric oxide, which should promote particle bonding. The separation of water and gangue can also increase bonding by solid reactions.

Studies on the Sintering Mechanism of Iron Ore Pellets. II. N. Nakamura and Y. Sato. (*Tetsu to Hagane*, 1957, **43**, July, 691–695). [In Japanese]. Kinetic data on the process of sintering of iron oxide pellets conform with Jander's equation for solid reactions. Two parts are distinguished in the process—" film " and " body " sintering—of which the former is important in relation to pelletizing.—K. E. J.

Research Leading to the Design of the Guest Keen Iron and Steel Sintering Plant. R. Parker. (*Blast Furn. Steel Plant*, 1957, **45**, Dec., 1395–1405). A report on pilot-plant trials carried out in order to design a new sinter plant at Cardiff is given. Particular importance was paid to the preparation of the raw mix in order to obtain optimum permeability. Pre-pelletizing of the mix is shown to have considerable advantages and has been adopted on the new plant.—B. G. B.

Some Experiences and Recent Developments in Sintering Australian Iron Ores. A. K. Farey. (*Proc. Australasian I.M.M.*, 1957, Sept., 107–152). Overseas development and trends in the quality of Australian ores are reviewed and the Newcastle sinter plant is described in detail with an account of its operation, construction, ignition and control. The results of research there and elsewhere are then considered. An appendix describes the experimental sinter boxes used.

FUEL—PREPARATION, PROPERTIES AND USES

New Approach to Coal Cleaning Efficiency. G. G. Sarkar. (*Min. Eng.*, 1957, **9**, Dec., 1361–1365). A sharpness index is developed relating to efficiency of separation.

Symposium: Planning a Coal Preparation Plant. H. B. Charmbury and J. W. Leonard. (*Min. Eng.*, 1957, **9**, Dec., 1326–1335). **Selection of Cleaning Units.** W. M. Bertholf, (1326). **Operation of Jigs.** A. P. Massmann. (1327). **Dense Medium Units.** H. E. Steinmann, (1327). **Wet Tables and Fine Coal Rheos.** J. Griffen, (1328). **Dry Tables.** W. C. McColloch, (1328). **Selecting Dewatering and Drying Equipment.** G. H. Kennedy and J. L. Walker jun., (1329–1332). A review of various types and their operation. (*Dewatering Screens*). O. T. Barrett, (1332). **Centrifuges.** W. L. McMorris. (1332–1333). **Thermal Driers.** E. R. McMillan. (1333). **Selecting Water Clarifying Equipment for a Coal Preparation Plant.** J. M. Vonfeld. (1333–1335). **Influence of Circulating Water Quality on Coal Preparation Plant Performance.** T. M. Larimer. (1335).

Investigation of Coking Properties of Scottish Coking Coals Used at Clyde Iron Works. W. Eland jun. and V. Giedroyc. (*J. West Scotland I.S.I.*, 1958, (504), pp. 31).

On the Manufacture of Moulded Metallurgical Coke from Inferior Coals. I. S. Ida. (*Tetsu to Hagane*, 1955, **41**, Sept., 929–931). [In Japanese].–K. E. J.

Coking of Lorraine Coals. L. Laurent. (*Technique Moderne*, 1957, **49**, July, 315–317). Coke for blast furnace use is reviewed.

Twenty Years of Coking at Port Kembla. R. D. Main. (*B.H.P. Tech. Bull.*, 1957, **1**, Oct., 18–21). A list of shutdowns is given and a note on blast furnace gas firing.

A New Interlocking System For Coke-Oven Battery Machines Employing a Radioactive Isotope. J. Zawels. (*Coke Gas*, 1957, **19**, Dec., 512–516). A γ-ray beam is used to synchronise the operation of a pusher and quenching car guide.

Significant Properties of Blast Furnace Coke. K. J. Figgis. (*Proc. Australasian I.M.M.*, 1957, Sept., 77–105).

Liquid Fuel Additives: Uses in Steelmaking. J. Firminger. (*Iron Steel*, 1957, **30**, Dec., 642–644). The author discusses the chemical and physical properties of liquid fuels, and considers certain benefits derived from the use of additives. Particular attention is given to the stabilization of fuels to prevent precipitation of high-molecular resinous and gummy constituents.—G. F.

The Oxidation Process of Carbon. K. Tamaru. (*Bull. Faculty Eng. Yokohama Nat. Univ.*, 1956, **5**, 97–101). Slow oxidation of acetylene black was studied by X ray methods.

TEMPERATURE MEASUREMENT AND CONTROL

Total Radiation Pyrometers for Temperature Measurement and Control. S. N. Howell and J. Jerger jun. (*Met. Treating*, 1957, **8**, Nov.–Dec., 10, 40, 41, 43, 47, 48). Infra-red measuring and control systems developed by the Servo Corp. of America are described, with typical circuits and response curves.

On the Casting Temperature as Measured by an Immersion Pyrometer. T. Kohira. (*Tetsu to Hagane*, 1955, **41**, Sept., 1030–1031). [In Japanese]. A correlation is given between temperatures obtained by immersion and optical pyrometers, and the effect of prolonged use on the readings is examined.—K. E. J.

Camera Maps Temperatures. (*Prod. Eng.*, 1957, **28**, Dec. 9, 86). An account of a photo-scanning thermistor device for temperatures from − 170 to + 300° C for large bodies is given.

REFRACTORY MATERIALS

Fundamental Aspects of Fireclay Research and Technology. R. W. Grimshaw. (*Refract. J.*, 1957, **33**, Dec., 528–535). Mineral types, compositions, strength of various kinds, changes on firing, refractoriness under load and examples of the application of these results to 3 samples are given.

Castable Refractories. A. E. Williams. (*Met. Ind.*, 1958, **92**, Jan. 3, 3–7). An account of aluminous cement and its metallurgical uses. Its uses in furnace linings and for foundry floors are described.

Problems Arising in the Manufacture of Fire-Clay Bricks of Very Low Porosity on Using Calcine-Fired Fire-Clay Grog. F. Tomšů. (*Hutn. Listy*, 1957, **12**, (12), 1149–1153). [In Czech]. Researches into production technology, which have led to the development of a process suitable for the manufacture of technologically acceptable bricks, are reported.—F. F.

Quality Control in a Refractories Plant. E. B. Hunt and K. K. Allen. (*Refract. J.*, 1957, **33**, Oct., 454–458, 460). Practice by the A. P. Green Fire Brick Co. is described. Control of raw materials, sampling, testing and grading, control during processing and manufacture and testing of finished products are reviewed.

Refractories and Mould Materials for Vacuum Melting and Casting. H. O. McIntire. (*Foundry Trade J.*, 1957, **103**, Nov. 7, 543–548). MgO and Al_2O_3 are reviewed and their properties given, as well as SiO_2, mullite and spinel. For higher temperatures, zirconia and zircon might be preferred. Steel is referred to but gas-turbine alloys are mainly considered.

Refractories for High Pressure Burners. (*Refract. J.*, 1957, **33**, Oct., 446–453). A tunnel burner from which the products are discharged at 1750–1850° C at supersonic velocity is discussed in relation to suitable refractories. Various designs are shown and uses are mentioned.

IRON AND STEEL—GENERAL

Prospects of Growth—Western Steel Industry. B. E. Etcheverry. (*Iron Steel Eng.*, 1957, **34**, Oct., 95–99). The reasons for the rapid expansion of the steel industry in West U.S.A. are discussed and it is suggested that this growth will continue at an accelerated rate to meet demand. The author estimates that some $1300 million will have to be spent to add about $4\frac{1}{2} \times 10^6$ ingot tons capacity.

Raw Material Supplies and the Future Development of the Iron and Steel Industry. C. R. Wheeler. (*J.I.S.I.*, 1958, June, **189**, 101–109). [This issue].

Steel: World Report: 1. The Development of Steel Production in the Far East. (*Steel Rev.*, 1958, Jan., 43–50). Statistical. **2. The Yugoslav Steel Industry.** (50–52). With map.

New Developments at Abbey Works, Steel Company of Wales, Ltd. W. F. Cartwright. (*Iron Coal Trades Rev.*, 1957, **175**, Dec. 20, 1419–1422). A lecture.

Expansion of Steel Industry in India. V. S. Swaminathan. (*Met. Prog.*, 1957, **71**, Jan., 73–76). The author gives details of the expansion of the steel industry proposed in India's second 5-year plan. The plan includes three entirely new Government-owned steel plants, to be built with technical help from Great Britain, Russia and West Germany.

The Steel Industry in India—Yesterday, Today and Tomorrow. E. T. Warren. (*Iron Steel Eng.*, 1957, **34**, Nov., 80–89). The author discusses the development of the iron and steel industry in India and outlines the present capacity. The current five-year plan will result in a gross annual capacity of 6×10^6 t, half of which will be made available from three new plants under construction.—G. F.

BLAST FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Equipment for the Iron and Steel Industry. I Blast Furnaces. (*Technique Moderne*, 1957, **49**, July). **Preparation of Blast Furnace Charges: Study of Sintering of Ore Fines and Blast Furnace Dust.** A. Mercier. (301–309). Making up the mixtures, mixing, ignition and distribution of constituents, grates, the Greenawalt and Dwight-Lloyd processes and typical installations are considered and illustrated. The rotary kiln is also described and costs are indicated. **Crushing and Screening of Iron Ores.** R. Godiniaux. (310–326). Types and installations of crushers are described, and screening before and after crushing is reveiwed with accounts of the installations at the Mine d'Hayange. **Injection of Fuel Oil into Blast Furnaces.** V. Redmond. (318–319). A review from the literature, with a table comparing ordinary operation with a system using enrichment to 26% O_2 and crude oil injection. **Comparison of [Bottom Discharge] Buckets with Skips for Blast Furnace Charging.** M. Brun. (320–323). Skips are preferred on the grounds of better distribution, safety, reduced handling and the possibility of sealing the furnace mouth. **Transport and Charging by Transporter Belts to the Seraing Blast Furnaces of the Société Cockerill-Ougrée.** L. Halbrecq. (324–326). An illustrated description of the conveyer system. **Modern Cowper Stoves and the Gerin Filling.** M. Gérin. (327–329). Modern zoned stoves and the Gérin checker-work are reviewed. **Blast Furnace No. 2 of the Société Metallurgique de Knutange.** M. Brun. (330–331). **Blast Furnace 5 of the Longwy Works.** M. Blanc. (332–333). **Purification of Blast Furnace Gas Wash Water.** R. Berchotte. (CIII).

Africa's Largest Blast Furnace Rises at Iscor. (*Engineer Foundryman*, 1957, **22**, Oct., 38–39). The welded construction is briefly described and illustrated.

Survey of Modern Blast-furnace Techniques. T. P. Colclough. (*J.I.S.I.*, 1958, June, **189**, 113–124). [This issue].

On the Progress of Iron and Steel Making Technique at Muroran Works. I. Murata. (*Tetsu to Hagane*, 1957, **43**, July, 738–744). [In Japanese]. Operating data over a 10-year period are summarized for the blast furnaces, coke ovens, steel plant, blooming mill, medium- and small-section mill and wire rod mill. Particular attention is given to use of coke-oven gas at high pressure, oxygen and high pig-iron ratios in the O.H. furnaces; pelletising techniques for using iron sand; and the magnetic roasting of limonite.—K. E. J.

Smelting Trials Using Swedish Ore Pellets. A. Reckmann and W. Misch. (**Stahl u. Eisen*, 1958, **78**, Jan. 9, 21–27). The trials were carried out with a burden in which magnetite, which is difficult to reduce and therefore requires a high coke rate, was replaced by Bodås pellets. The trials and their results are reported in detail. Although they were satisfactory the works involved decided to

build a sintering plant and not a pelletizing plant for reasons that are discussed at length.

On the Chemical Reaction Between Carbon-Saturated Molten Iron and CaO–Al_2O_3–SiO_2 Slag. II. The Effects of FeO, MnO and Na_2O Additions. M. Soga. (*Tetsu to Hagane*, 1955, **41**, Sept., 1008–1009). [In Japanese]. Graphs are shown of the following relationships: residual FeO content of slags, kind of slags, melting times and sulphur content of the iron; Al_2O_3 content of slags and desulphurizing power of CaO–Al_2O_3–SiO_2–FeO slags; and Al_2O_3 contents and desulphurizing power of basic slags with and without MnO additions.

The Equilibrium of Carbon and Oxygen in Molten Iron Saturated with Carbon. S. Banya. (*Tetsu to Hagane*, 1955, **41**, Sept., 1012–1013). [In Japanese]. Experimental results at 50° intervals between 1300° and 1600° C are correlated with the theoretical equilibrium and with thermodynamic relationships.—K. E. J.

Equilibrium of Carbon and Oxygen in Molten Iron Saturated with Carbon. I. S. Matoba and S. Banya. (*Tetsu to Hagane*, 1957, **43**, Aug., 790–796). [In Japanese]. The equilibrium was studied at 1300–1600° C by melting iron–carbon alloys in a graphite crucible in a CO–CO_2 atmosphere. Carbon decreased the activity coeff. of O_2 in molten iron, and large values were obtained for the products of C and O_2. Thermodynamical relationships are given for these deductions, and for the solubility of graphite. (18 references).—K. E. J.

Lime Powder Desulphurisation Proves Practical, Efficient. (*Iron Age*, 1957, **180**, Oct. 31, 66–67). Results of investigations by IRSID into ladle-desulphurization of pig iron are described. The method involves blowing lime powder, suspended in air or nitrogen, into the iron ladle through tuyeres. Sulphur may be reduced to below 0·01% from 0·3% in 3 to 5 min. The blowing medium, metal temperature, and blowing method affect the results. 12-t heats have been treated, and one French plant is installing equipment to deal with 1000 t per day.—D. I. C. P.

Influence of Alkaline-Earth Metal Oxides on the Distribution of Sulphur between Iron and Iron-containing Slag. L. A. Shvartsman, I. A. Tomilin, O. V. Travin and I. A. Popov. (*Problemy Metallovedeniya i Fiyika Metallov, 4th Collection. State Publishers for Ferrous and Non-Ferrous Literature, Moscow*, 1955, 577–594). A tracer element study is reported. A temperature dependence of S-distribution was found and the thermal coefficient calculated. The effect of added oxides can be explained without assuming the formation of alkaline-earth sulphides in the molten slag.

Studies on the Desulphurisation Reaction of Molten Iron with Gas. I. Measurement of Rate Constant of Desulphurisation with Oxygen Gas. Y. Katsufuji and K. Niwa. **II. with Hydrogen Gas.** Y. Katsufuji. (*Tetsu to Hagane*, 1957, **43**, Aug., 796–801; 802–806). [In Japanese]. I. In molten Fe–C–S alloys the desulphurization reaction with O_2 was first-order with respect to sulphur content. Re-carburization and the carbon removal reaction were shown to take place independently in the melt. Rates of desulphurization were influenced by the carbon content, and the specific rate constants were smaller than those of lime slags.

II. In molten Fe–S and Fe–S–C alloys the desulphurization reaction by H_2 was first-order with respect to sulphur. Rates of desulphurization were influenced by the sulphur and carbon contents. The rate constant was larger than that of O_2 gas but smaller than that of lime slag.—K. E. J.

Thermodynamics in Pyrometallurgy. J. W. Evans. (*Research*, 1958, **11**, Jan., 12–18). A review. The blast furnace reduction process and other ferrous and non-ferrous extraction methods are treated on a thermodynamic basis and the energetics of liquid steel and slags are also discussed. Brief accounts of Cu, Al and U are also given. (27 references).

On the Relation between the Inactive Central Core Measured at Tuyere Level and Blast Furnace Operation. T. Noji. (*Tetsu to Hagane*, 1955, **41**, Sept., 941–943). [In Japanese]. Operating data show a reciprocal tendency between the area of the central core and the ratio of blast pressure to blast volume. An inverse linear relationship is shown between the distance from the tuyere to the core and the difference in CO_2 percentage between a point 750 mm from the wall and at the wall side. A relationship is also sought between coke rate and the area of the core in stable operation.—K. E. J.

Theoretical Limitations of Blast Furnace Operation. H. Suematsu. (*Tetsu to Hagane*, 1955, **41**, Sept., 1004–1006). [In Japanese].

Effect of Size of a Blast Furnace on Its Performance. H. Wünnemann, W. Loorz and W. Oelsen. (*Stahl Eisen*, 1957, **77**, Dec. 26, 1854–1862). The relationship between output, iron quality and production costs was studied on four blast furnaces of different sizes over a period of several years. Coke consumption and costs of the iron produced show a min. at a definite coke consumption rate; increasing the hearth diameter reduces both coke consumption and cost of the iron. The reason for this is explained and discussed. On the other hand, smaller furnaces usually produce a better quality iron, and it is easier to control and to vary the iron quality in a smalier than in a larger furnace.—T. G.

A Study of the Movement of Materials in the Blast Furnace by Means of Radioactive Isotopes. I. G. Polovchenko. (*Stal'*, 1957, (12), 1057–1068). A device for introducing ampoules containing tracers is described and the arrangements made for counts in the tuyere and in the hearth. Movements of coke and ore are shown in a diagram. The rates of movement in the upper part of the stack are not uniform across the cross-section. The rate is lowest in the wall zone and highest at the furnace axis and about 2 ft. from the wall. Some lumps of the charge supporting the burden in the upper part tend to move into the axial region. Lower down, a zone of more intensive motion occurs and coke tends from the axis to the walls due to the different rates of movement in concentric zones of the cross section. Horizontal movement of lumps 40 mm in dia. and 60 mm long reaches 1270–2500 mm. The ore outstrips the coke in the bosh and lower part of the stack rather less than the average down to tuyere level. After melting the ore moves much more rapidly than the coke and arrives at tuyere level at twice its rate. The time of arrival can be calculated. At this level the coke may move in a circular course for some time and may move from one tuyere hearth to another. Coke falling below the oxidizing zone may circulate or may return. The CO_2 content depends upon the rate of burden movement as well as on the coke-to-ore ratio.—R. S.

Studies on the Controlling Factors for Blast Furnace Operation for Various Reducing Processes in the Furnace. S. Kamatani. (*Tetsu to Hagane*, 1955, **41**, Sept., 939–941). [In Japanese]. A ratio k_2 is defined in terms of CO_2, CO and N_2 in the gas. Correlation coefficients are established between this and various operating parameters. An inverse linear relationship, with much scatter, is shown between k_2 and the ratio (wind volume)/(blast pressure). Curves with a maximum are shown for corrected coke rate against k_2, at two values of a further parameter G.—K. E. J.

Some Effects of Charging Size on Blast Furnace Operation. (*Tetsu to Hagane*, 1955, **41**, Sept., 945–947). [In Japanese]. Eight sets of weekly data are presented, giving values for output, coke rate, iron quality and other operating data against ore sizes and analyses and charging sequences. Figures are also given for the CO and CO_2 analyses 3·3 m and 0·7 m below the stock line.

On the Use of Iron Sand for Blast Furnaces. Y. Imao. (*Tetsu to Hagane*, 1955, **41**, Sept., 943–945). [In Japanese]. Details are given of sintering practice with up to 30% of iron sand in the ore. A reciprocal tendency is shown between TiO_2 content and slag basicity. A TiO_2 balance is given, and a relationship between TiO_2 and fluidity is explored.—K. E. J.

Permeability of Blast Furnace Burdens. N. Kikuchi. (*Tetsu to Hagane*, 1955, **41**, Sept., 933–934). [In Japanese]. Coke, ore and total burden are analysed for particle size fraction, permeability after progressively removing fractions, and the relationship between bulk density and the size fraction.—K. E. J.

On the Desulphurisation of Pig Iron by Slag in the Blast Furnace. J. Sawamura. (*Tetsu to Hagane*, 1955, **41**, Sept., 1009–1011). [In Japanese.]—K. E. J.

A Study on the Coke Rate of Blast Furnaces. Y. Togino. (*Tetsu to Hagane*, 1955, **41**, Sept., 1006–1008). [In Japanese.]—K. E. J.

On Slack-Wind Blowing in Hirohata Blast Furnaces. S. Otabe. (*Tetsu to Hagane*, 1955, **41**, Sept., 947–948). [In Japanese].—K. E. J.

Use of Fusite in Desulphurizing Off-Grade Pig Iron. J. Goswami, A. B. Chatterjea and B. R. Nijhawan. (*J. Sci. Ind. Res.*, 1957, **16A**, Nov. 522–526). "Fusite" is fused soda ash. Trials with pig iron containing over 0·06% S in an acid-lined ladle are detailed, and the mechanical properties of treated and untreated irons are given. Excess fusite does not improve sulphur removal and in basic-lined ladles the lower the initial S the lower the efficiency of its removal.

Study on the Blast Furnace Reaction by Rapid Cooling of Burdens. N. Nakamura and Y. Sato. (*Tetsu to Hagane*, 1957, **43**, Aug., 785–790). [In Japanese]. Conditions in an experimental low-shaft furnace of oval section, of capacity 0·6 cu.m. (equivalent to 1 t of iron per day), were investigated by rapid cooling of the burden with nitrogen. With a charge of pellets, change of pellet shape began in the lower half of the bosh, and slag formation was observed. The pellets were weakened half-way down the shaft, but the refractoriness-under-load increased with the degree of reduction.—K. E. J.

A Blast Furnace Salamander: Some Structures Observed. H. C. Coe and C. G. Brown. (*B.H.P. Tech. Bull.*, 1957, **1**, Oct., 30–31). Two salamanders found during the destruction of a blast furnace are described. The upper weighing 148 t was liquid at the time of shut down and was separated by a foot of brickwork from the lower of 240-t. The lower salamander was bricked in in 1951 and had been heat treated ever since at about 800–900° at the top to 200–300° at the bottom. Structures are shown.

Control of Gas Streams by Changing the Length and Cross-Sectional Area of the Tuyeres. M. K. Ivanov. (*Stal'*, 1957, (12), 1071–1073). During repairs at the Kushvinsky Plant, steep or vertical boshes were built with a low ratio of throat to hearth dia. This caused peripheral working, increase of coke consumption, and channeling. Improvement was effected by lengthening the tuyeres and results related to length are shown. A fixed relationship between throat dia. and length of tuyere projecting was found.—R. S.

Improvement of the Design of a Hot Blast Valve. L. Ya. Matusevich. (*Stal'*, 1957, (12), 1073–1076). Increase of blast temperature to 850–900° required a new type of valve, copper discs and rings were replaced with welded low-C steel coated with Al 0·15–0·2 mm thick. The body and lid are water cooled. Plastic modes were used to discover the causes of failure and the new design is shown. Arrangements for regular removal of sludge deposits are made.—R. S.

Study on the Manufacture of Pig Iron and Portland Cement in Blast Furnaces. I. K. Takahata. (*Tetsu to Hagane*, 1955, **41**, Sept., 1015–1017). [In Japanese.]—K. E. J.

New Methods of Ironmaking. H. Schenck. (*Iron Coal Trades Rev.*, 1957, **175**, Dec. 13, 1363–1364). Effects of coke and scrap shortages are considered. The low shaft furnace and sponge iron processes are reviewed.

Gas and Air Failure Safety Equipment for Hot-Blast Stove Burners. H. Stempel. (*Demag News*, 1956, (146), 19–24).

Pre-Refining of Basic Pig-Iron with Oxygen. L. Kodrle. (*Hutn. Listy*, 1957, **12**, (12), 1070–1077). [In Czech]. A number of pig irons taken from the mixer or directly from the blast furnace and varying in composition, the latter having on the average 0·50% Si, 2·20% Mn, 1·65% P and 0·09% S, were pre-refined with the oxygen lance, using O_2 of 97·5% purity. At the point of impingement, temperatures rose to between 2000–2500° C. A statis-

tical analysis of the compositions after pre-refining showed that with irons having the usual standard composition the process leads to a reduction of the Si, Mn and C contents by 0·2, 0·9 and 0·1% respectively, and is economical. The pre-refining took place without slag treatment. The bath temperature rose by 80–140° C during the blow with a specific O_2 consumption of 5·6 m³/ton. The results are shown to agree satisfactorily with theoretical expectations; the relation between the contents and losses of Mn and Si was clearly apparent.—P. F.

PROPERTIES, TREATMENT, AND USE OF SLAGS

On the Electrical Conductivity of CaO–SiO_2 and FeO–CaO–SiO_2 Slags. K. Ogino. (*Tetsu to Hagane*, 1955, **41**, Sept., 948–949). [In Japanese.] The relationship between specific conductivity and concentration of CaO in CaO–SiO_2 slags is shown graphically for 1550° and 1600° C, and the relationship between specific conductivity and concentration of FeO in FeO–CaO–SiO_2 slags is shown for CaO/SiO_2 ratios of 1·0, 0·8 and 0·6.—K. E. J.

Electrical Conductivity of Oxidised Slags. A. Adachi and K. Ogino. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1957, **7**, Mar., 121–126). Iron oxide slags were melted in Pt crucibles in air and the conductivities measured under conditions in which the iron was practically all in the ferric state. Conductivity increased with Fe content and with temperature and appears to be mainly ionic. Some slags show a sudden decrease below solidification temperature.

The Rapid Analysis of Steelmaking Slags. S. Muir and A. D. Ambrose. (*Metallurgia*, 1957, **56**, Nov., 255–257). The authors describe a rapid method for the complete solution of steelmaking slags and other silicate materials, entailing fusion in a mixture of sodium carbonate and borax followed by extraction in dilute nitric acid and hydrogen peroxide. A subsequent spectrographic technique for slag analysis is described. A single analysis takes 35 min. and the standard deviation is not more than ± 3% of the content.—G. F.

DIRECT PROCESSES

The Case for Direct Reduction. (*Steel*, 1957, **141**, Oct. 28, 180–192). The future of alternatives to the blast furnace process is considered, and the nature of the processes reviewed. A table summarises details of 14 projects. One incentive is reduction of capital outlay with the new methods; these have yet to prove they are capable of large scale, reliable output for the U.S. Market.—D. L. G. F.

Measuring Flue-Dust Emission from Krupp-Renn Rotary Kilns. F. Černý and O. Vicherek. (*Hutn. Listy*, 1957, **12**, (12), 1065–1070). [In Czech]. Works experiments on flue dust emission showed that recirculation of flue dust into the furnace head results in (*a*) an increase in the flue-dust content in the flue ducts of the furnace by 21%, (*b*) a decrease by 29% of the proportion of combustible materials in the flue gas and a parallel increase of ash by 2·3%, and (*c*) an increase in the proportion of fines in the flue dust. It is concluded that recirculation may result in an increase in the contamination of the surroundings of the sintering plant by volatile effluents.—P. F.

Refining with Oxygen in the Kaldo Rotary Converter. B. Kalling and F. Johansson. (*Stahl Eisen*, 1957, **77**, Dec. 26, 1885–1887). This is a supplement to the author's previous report (*ibid.*, **77**, 1308). The lining of the rotary converter has been improved and details of this are given. The heat balance of the converter is discussed with particular emphasis on the possibility of burning the CO almost completely to CO_2. The O_2 content of the melt blown in the Kaldo rotary converter is the same as that of O.H. steels; the variations in the O_2 level are consistently low; this is an important factor in the production of semi-killed steels.—T. G.

PRODUCTION OF STEEL

Trends in Design and Mode of Operation of Modern Integrated Iron and Steel Works. P. Rheinländer. (*Stahl u. Eisen*, 1958, **78**, Jan. 9, 1–12). The steadily increasing demand for steel in the world requires new methods of production. The author describes the design and operation of the Hüttenwerk Salzgitter as an example of this trend, as this works has recently been completely rebuilt incorporating the latest features, it is situated near the ore source—low-iron and silica-rich ore—and has no coal source of its own. Design and operation including ore preparation are described in detail.—T. G.

Application of Static Switching in the Steel Industry. D. L. Pierce. (*Iron Steel Eng.*, 1957, **34**, Nov., 113–123). The author discusses the basic functions of digital control systems using static components, and describes a number of applications of such systems in the steel industry. The adoption of relatively complex automatic control is justified by increases in quality production as a result of consistent and accurate control at optimum efficiency.—G. F.

Increased Production of Special Steels. (*Overseas Eng.*, 1958, **31**, Jan., 214–215). An account of work at Hadfields Ltd., East Heela Works.

Practical Measures to Prevent Abnormal Wear in a Steel Mill. J. De Vries. (*Wear*, 1957, **1**, Dec., 239–243). General rules are given and applications to wire ropes, pump shaft seals, the working of bearings in dusty locations and to tubes carrying coke-clay-water mixtures in foundries are briefly indicated.

The Manufacture of Steel by the Oxygen Lance. W. S. Williams. (*Brit. Steel.*, 1957, **23**, Dec., 378–379). A method of blowing avoiding skull formation by splashing in which blowing is continued until (under suitable conditions) increasing viscosity of the bath stops the flow of oxygen.

An Oxygen Steelmaking Process. F. W. Luerssen, J. W. Halley, and M. Tenenbaum. (*Trans. A.I.M.M.E.*, 1957, **209**, *J. Met.*, 1957, **9**, Dec., 1533–1540). The authors describe an oxygen steelmaking process which is suitable for American raw materials, and discuss the results of experiments carried out in small and large heats to determine the operating and refining characteristics of the process. High carbon, low phosphorus steel, identical with basic O.H. steel, can be made from pig iron containing 0·7% P, in commercial-sized O.H. furnaces with no external heat for refining.

Enriched Blast in Basic Steelmaking. P. Coheur and H. Kosmider. (*Met. Prog.*, 1957, **71**, Jan., 67–72). The authors first review some of the pneumatic steelmaking processes first considered by Bessemer, in addition to his bottom-blowing process, and compare these methods with O.H. steelmaking. European developments in pneumatic processes involving the use of oxygen are then discussed and are shown to produce steels equivalent in quality to O.H. steels.—G. F.

On Blowing Oxygen of Low Purity into the Steel Bath. T. Kajiwara. (*Tetsu to Hagane*, 1955, **41**, Sept., 955–957). [In Japanese]. Results with 100%, 70% and 50% pure oxygen during melting and refining show that, although the decarburising velocity falls as the oxygen becomes less rich, the decarburising efficiency increases; the latter efficiency is defined as the ratio of theoretical quantity required for the carbon removed to the actual oxygen quantity blown in—K. E. J.

The Effect of Hydrogen on the Production of Steel in the Oxygen–Steam Converter Process. H. Neuhaus. (*Stahl u. Eisen*, 1957, **77**, Dec. 26, 1863–1867). The theory of H_2 pick-up during the blowing period in the oxygen–steam converter process and for the solubility of H_2 in steel is discussed. The H_2 levels at the end of the blowing period are usually higher when steam is added to the O_2 than when it is omitted. After-blowing with H_2-free gases reduced the H_2 content substantially, further reduction was observed during hot rolling. No difference in the H_2 levels of the finished products was found.—T. G.

Practical Study on Low-carbon Rimmed Steel Making. II. Change of Oxygen and other Elements during Oxygen Injection, and [Determination] of the Optimum Tapping Period. K. Izu. (*Tetsu to Hagane*, 1957, **43**, Mar., 242–244). [In Japanese]. It is shown that the O_2 content in liquid steel is at a maximum at the end of O_2 injection, falls to a minimum after some 15 min, and then rises to a value higher than the previous maximum as the time further increases by 10 min or more. The amount of FeO in the slag follows a similar trend. Reduction of the time from the end of O_2 injection to Fe–Mn addition brings about a corresponding reduction in the amount of the Al addition needed.—K. E. J.

Evaporation of Iron During Blowing of Pig Iron in a Convertor. P. Ya. Sorokin. (*Izvest. Akad. Nauk, S.S.S.R., Otdelenie Tekh. Nauk*, 1956 (8), 28–36). [In Russian]. During the blowing of iron in convertors due to local over-heating of the surface of bubbles their saturation with iron vapours takes place. The vapour-pressure of iron in the bubble will depend on its local temperature. During the passage of the bubble through the metal of a lower temperature, its temperature decreases and a partial condensation of iron vapour takes place forming very fine particles of iron (iron mist). At the outlet of the convertor, iron vapour and iron mist are rapidly oxidized forming iron fumes. With decreasing carbon content in the blown metal the relative velocity of oxidation of iron increases, increasing the thermal balance of the bath as a whole and that of local bubbles, in particular. Due to increased supply of heat the evaporation of iron increases, producing copious fumes at the outlet at the end of the blow. Blowing of metal with oxygen causes a sharp increase of iron losses due to evaporation.

New Type of Open Hearth Furnace Charging Door Frame. G. A. Sokolov. (*Metallurg*, 1957, (3), 38–39). Disadvantages of complex welded plate frames are noted and a new design of H-frame from seamless tubes is shown. These are particularly useful when the pressure in the hot-cooling system is raised from 2 to 4½ atm.

The New Open-Hearth Steelworks of the Société Usinor à Denain. R. Thibaut and A. Delcamp. (*Acier-Stahl-Steel*, 1957, **22**, Mar., 97–104). The buildings and their construction are described.

Open-Hearth Steelworks of La Sollac at Sérémange. A. Delcamp. (*Acier-Stahl-Steel*, 1957, **22**, Mar., 105–107). An illustrated account is given of the construction.

The Aerodynamic Constitution of the Open-Hearth Furnace. Standard Dimensions of the Single Air-Uptake Furnace. H. A. Hasimoto. (*Tetsu to Hagane*, 1957, **43**, Mar., 355–357). [In Japanese].—K. E. J.

Effect of Partial Reconstruction of the Open-Hearth Furnace. K. Matsunaga. (*Tetsu to Hagane*, 1957, **43**, Mar., 219–220). [In Japanese]. Laboratory investigations showed that improvements could be made to a furnace by making the upper part of the rear wall incline slightly forwards instead of backwards (angle of 136° to the roof instead of 98°). This reduced eddies in the gas and produced a more even flow into the centre of the furnace.

Operation of the All-basic Open Hearth Furnace. C. Okawa. (*Tetsu to Hagane*, 1957, **43**, Mar., 295–297). [In Japanese]. The physical and chemical properties of Radex-E refractory are described. Detailed results are given for furnace operation over several months, showing more efficient practice with the all-basic furnace with Radex-E than when it had a basic panel and silica bricks.—K. E. J.

Combustion Properties and Reconstruction of the Siemens-Type Furnace. K. Nakamachi. (*Tetsu to Hagane*, 1957, **43**, Mar., 311–312). [In Japanese].—K. E. J.

On Recent Practice with the Open Hearth Furnace in the Tsurumi Steel Works. A. Matsushiro. (*Tetsu to Hagane*, 1957, **43**, Mar., 225–226). [In Japanese].—K. E. J.

The Construction and Operation of New Open Hearth Furnace Shop in Kawasaki Iron Works, Nippon Kokan Kabushiki Kaisha. J. Shiramatsu, (*Tetsu to Hagane*, 1957, **43**, Mar., 335–336). [In Japanese].—K. E. J.

Increasing Open Hearth Capacity—Fuel's Contribution to Increased Open Hearth Capacity. C. W. Dunn. (*Iron Steel Eng.*, 1957, **34**, Aug., 57–64). This article describes the dual fuel

(oil and tar) system and method of delivery to the 330 t basic O.H. furnaces at Fairless. Details are given of special tests carried out to increase productivity, these include flame radiation, preheated air temperature, air infiltration studies, dust tests and exhaust gas volume studies.—M. D. J. B.

Increasing Open Hearth Capacity by Extending the Hearth. C. D. Guth. (*Iron Steel Eng.*, 1957, **34**, Aug., 64–69). The effect of increasing hearth capacity on productivity is examined. The example described is of a 75-t O.H. furnace redesigned for liquid fuel firing and 135-t capacity.—M. D. J. B.

Increasing the Capacity of an Open Hearth Shop. M. K. Morris. (*Iron Steel Eng.*, 1957, **34**, Aug., 69–72). Details are given of the modifications carried out in the Nos. 2 and 4 O.H. shops of Bethlehem's Saucon Division plant. Furnace sizes were increased from 130–160 t and numerous improvements were made to furnace stage, handling, charging and rail facilities, etc.—M. D. J. B.

The Use of Unburnt Magnesite–Chromite Bricks in Open Hearth Furnace Roofs. S. M. Broit. (*Stal'*, 1957, (9), 792–795). In main roofs of 100-t furnaces the campaign was doubled as compared with silica. Zebra roofs were first used with 16 ft height of arch and 180–200 heats were obtained working on the scrap and ore process with hot metal and a mixture of blast furnace gas and liquid fuel. Roof construction is shown with a view after 172 casts. Up to 450 heats were obtained and with the suspension used repairs could be done when the fuel was turned off. To retard cooling, the doors were not opened until 4 h after this. The gas port roofs were also lined with MgO–chrome brick and they still operated after 355 heats. A roof life of up to 600 heats with one partial intermediate repair to the upper part of the walls and part of the roof can be obtained. It is recommended that the upper parts of the walls and the entire top should be MgO–chrome and that any part of the lining showing red should be cooled with compressed air.—B. S.

Use of Sinter in the Open Hearth Furnace. N. A. Vecher, A. A. Lebedev and N. D. Korneev. (*Metallurg*, 1957, (6), 17–19). Owing to shortage of ore, 66·3% sinter was charged at Nizhni Tagil for rimming, killed, C and alloy steel production in acid and basic 140, 260 and 380 ton furnaces. Consumption of sinter is higher than that of ore and more slag is made. Tap-to-tap time is reduced by 12–15 min. For a given content of P in the iron, lower P is obtained in the steel with sinter than with ore (0·002–0·012% lower) and C is eliminated more rapidly during the ore boil.

Attempts to Use Oxygen in Open Hearth Furnaces Working for Foundries. J. Wojtow. (*Przeglad Odlewnictwa*, 1957, **7**, Feb., 40–41). [In Polish]. The author describes and tabulates data on the experimental introduction of O_2 in O.H. furnace. Five trials have been made which are not sufficient to draw definite conclusions, but indicate an improved heat efficiency.

Advantages of Automatic Flame Reversal in Open-Hearth Furnaces. V. Parma. (*Hutnické Listy*, 1957, **12**, (7), 578–585). The principle of flame reversal and the systems used are described and it is shown that it improves thermal efficiency and increases checker work life. Operation is also simplified giving more time for management of the melts.

Study on Melting Practice in the Tilting O.H. Furnace. Manganese Behaviour in the Refining Process. S. Miura. (*Tetsu to Hagane*, 1957, **43**, Mar., 245–247). [In Japanese]. Previously reported and practically-obtained results showing the effect of slag basicity on the Mn equilibrium are correlated. Results with considerable scatter are put forward to show a relationship between $([Mn]-[Mn]_{eq})$ and reaction velocity. Bath and slag analyses for Mn and slag constituents are given, at intervals up to 90 min after adding Mn ore, CaO and SiO_2.

Carbon Removal [from] Mild Steel in the Basic Open Hearth. T. Fujii. (*Tetsu to Hagane*, 1957, **43**, Mar., 373–375). [In Japanese]. The removal of carbon is studied thermodynamically, with reference to carbon removal rates and the C–O equilibrium in high-frequency furnaces with N_2 atmospheres. The rates of carbon removal in the O.H. furnace and in high-frequency furnaces with atmospheres of 100% and 99% N_2 are compared.—K. E. J.

Influences of Flush-off Type on Open Hearth Practice. H. Nakagawa. (*Tetsu to Hagane*, 1957, **43**, Mar., 247–250). [In Japanese]. Slag compositions and metal analyses at various periods and other operating data are given to compare free and controlled flushing practices.

Behaviour of Hydrogen in Steel in the Basic Open-Hearth Process. T. Obinata. (*Tetsu to Hagane*, 1957, **43**, Mar., 223–225). [In Japanese]. The variation of H_2 concentration is followed during melting and refining: and before, during and after O_2 blowing.—K. E. J.

On Heat Conduction in the Open Hearth Furnace. M. Maezawa. (*Tetsu to Hagane*, 1957, **43**, Mar., 297–298). [In Japanese]. After a theoretical treatment, a comparison is made between the gas radiation capacity and the radiation efficiency. Data are given relating the inside wall temperature and the heat transfer to the molten metal, and the gas temperature to the inside wall temperature.

Behaviour of Open Hearth Bath Temperature. D. Yoshinari. (*Tetsu to Hagane*, 1957, **43**, Mar., 244–245). [In Japanese]. The variations of temperature, horizontally and vertically, are followed between reversals, and a relationship is shown between rate of rise of bath temperature at 1600° C and thickness of slag.—K. E. J.

Thermal Conditions in the Open Hearth Process with Phosphoric Pig Iron Using Oxygen. I. A. Zaitsev. (*Stal'*, 1957, (9), 788–792). The main factor determining the rate of temperature rise during the boil is the consumption of O_2 per hr. With high-P iron the slag and metal are far from equilibrium in rate of P oxidation. During the boil the temperature increase accelerates P removal, improves dephosphorizing capacity of slag and improves kinetics of P oxidation, but it retards the progress of the reaction and displaces the equilibrium unfavourably. At any stage there is an optimum temperature for maximum P oxidation and the period depends on slag composition, the temperature is higher as CaO increases and as Si falls. Under the conditions used the optimum temperature of the boil was 1480–1500°. In a 350-t furnace the best conditions were obtained with a rise of 130°C/hr from the introduction of O_2 at 1200–1300 m³/hr. Further intensification can be attained by forming a ferruginous limestone slag.—B. S.

On the Question of Computation and Evaluation of Heat Balances for the Open-Hearth Furnace. V. Balabanov. (*Hutnické Listy*, 1957, **12**, (7), 604–609). The heat balances should show clearly the characteristics of the furnace and also those of the various sections. Measurement of temperature requires flow thermometers and not thermocouples and metal temperatures should be measured with two-colour on immersion pyrometers and not with one-colour instruments. The amount of producer gas can be measured on a Venturi tube. A numerical example is given showing the importance of standardizing the measurements.

[Rapid Determination of Basic Open-Hearth Slag Basicity, by pH and SiO_2 Determination]. II. T. Shimose. (*Tetsu to Hagane*, 1957, **43**, Mar., 393–395). [In Japanese]. The information includes graphs showing the effects of CaO content, SiO_2 content and slag basicity on the pH value.—K. E. J.

Oxidising Power of Basic Open Hearth Slags. H. Kunitake. (*Tetsu to Hagane*, 1957, **43**, Mar., 376–377). [In Japanese]. The relationship between iron oxide content in slag and carbon content in the basic O.H. bath is shown for various slag basicities. Slag behaviour in the basic O.H. process is depicted in a ternary diagram between (CaO + MgO + MnO), ($SiO + P_2O_5 + Al_2O_3$) and FeO.—K. E. J.

The Fundamentals of the Rapid Melting of Heats of Kh21N11V2·5 Steel. V. V. Panin. (*Liteinoe Proizvodstvo*, 1957, (1), 11–14). [In Russian]. Practice at two Soviet works for the melting of a heat resisting steel (0·1–0·25% C, 0·6–1·4% Si, 0·6–1·2% Mn, 19–23% Cr, 10·5–13% Ni, 2·4–3% W, 0·2% Ti) is compared and information on the metal properties is given. The practices compared differ mainly in the conduct of diffusional deoxidation: at the Moscow Machine Construction works a new slag and gradual addition of the mixture are used, while at the Ural works the mixture is added in one or two batches to the old slag whose fluidity is increased by lime additions. The latter gives a faster heat and, as shown by the comparative data, an equal or superior product, with the possibility of extracting valuable metals from the slag.—S. K.

Raising the Capacities of the Stock Yard and Mould Preparation Shop. I. I. Bornatskii, A. P. Zubkov and V. I. Prilepskii. (*Stal'*, 1957, (9), 796–800). Improved operation and organization in an O.H. department have considerably increased capacity.

Mobile Ventilation Apparatus for Siemens-Martin Furnaces. V. Drobota. (*Met. Constr. Masint*, 1956, **8**, (2), 45–47). This apparatus evolved in Russia by Outcheastkin and Landa in 1949, allows access into an incompletely cooled oven, so that repairs can be executed without great loss of time. Successful tests with this apparatus have now been concluded.—L. H.

The New Electric Steelworks of the Creusot Co. (*Usine Nouvelle*, 1957, Sept., Edn. Mensuelle, 5). Installation of 2 80-t furnaces in the Breuil works is described.

On Recent Advances in Electric Arc Furnace Operation at the Sumitomo Steel Works. M. Nishigishi. (*Tetsu to Hagane*, 1957, **43**, Mar., 336–338). [In Japanese]. For a 15-ton Héroult furnace, details are given of furnace dimensions and equipment, an improved electrode lifting device, linings, operating practice, and improvements in performance.

The Effect of Variables on the Melting Rate of Metals in the Consumable Electrode Arc Furnace. W. H. Smith. (*Arcs in Inert Atmospheres and Vacuum*, 1956. *Symposium of Electrothermics and Metallurgy Division of the Electrochemical Society, Apr.-May*, 41–56). Melting rates were measured as functions of crucible-to-electrode size ratio, power input, melting pressure and type of electric circuit for iron and other metals.

Melting of Austenitic Chrome–Nickel Steels from Similar Scrap, Using Pure Oxygen in a Basic Arc Furnace. R. Peters. (*Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin*, 1956, 76–90). In order to achieve high recovery of alloying elements it is essential to work at high temperatures as shown by thermodynamic considerations. These high temperatures are obtained by using high refining rates and use of heat from exothermic reactions. Desulphurization and dephosphorization were not achieved during refining with oxygen, but the nitrogen content was decreased. The behaviour of Si and Mn is also discussed. (18 references).—R. P.

Mechanisation and Automation of the Oxygen Feed to the Bath of Electric Arc Furnaces. G. S. Sel'kin and N.P. Zadalya. (*Metallurg*, 1957, (2), 8–11). The use of iron tubes for the introduction of O_2 is not recommended for heavy tonnage production in large furnaces. At the Zaprorozhe works over 200 miles would be required annually for the O.H. furnaces and the arc furnaces at Dnyeprospetstal would require 150 miles. A device consisting essentially of a water-cooled copper nozzle is therefore used. Tests with multi-jet ports were made and a type selected for arc furnace use. The nozzles are automatically raised if the pressure drops, cooling water temperature falls or if the nozzle is choked. It is also lowered automatically when the O_2 is turned on.

On Dust Collection in the Electric Furnace. I. M. Haga. (*Tetsu to Hagane*, 1957, **43**, Mar., 370–372). [In Japanese].—K. E. J.

Low Alloy MK Steel for Large Welded Structures. A. V. Prokhorov. (*Stal'*, 1957, (9), 829–833). This steel, with 0·12% C, 1·3–1·65% Mn, 0·8–1·2% Si, 0·15–0·40% Cu, 0·3% max. Cr and Ni, 0·045% max. S and P, was developed for the gas main between Kiev and Moscow. Properties are given and an account of melting, rolling and welding.—B. S.

Properties of Cast Alloy Structural Steel. B. B. Gulyaev, I. A. Shapranov, V. M. Shpeizman, and P. E. Kovalenko. (*Liteinoe Proizvodstvo*, 1957, (2), 11–16). [In Russian]. The results are presented of a comparative investigation of the mechanical and technological properties of some of the main types of cast structural steels alloyed to different degrees and of one carbon steel. The steels were melted in 0·5 and 3·0-t electric furnaces and cast into bars with wall-thickness varying from 12–100 mm from which the mechanical test-pieces were cut. The bars were subjected to annealing or normalization in preliminary treatment at 860–900° C for 2, 4 or 5 hr, to normalization and hardening at 850–880° C for 2, 3 or 4 hr and tempering for 3, 4 or 5 hr at 640–680° C. Plots of the Brinell hardness, toughness, relative elongation and contraction, the yield-point and ultimate strengths against tempering temperature and wall thickness after normalization and after hardening are shown. The results show that the use of alloy instead of carbon steels enables casting strength to be increased appreciably without loss of plasticity. Hardenability tests were also carried out, the plot of the results showing that the alloy steels differ somewhat among themselves and all have a higher hardenability than the carbon steel. The tendency to temper brittleness was found to differ little at ordinary temperatures, but great differences appeared at low temperatures. High-temperature mechanical tests and measurements of liquid steel fluidity were also carried out, several carbon steels being used for the latter. Other studies included hot cracking, to which, as confirmed by service tests, the alloy steels were found to be somewhat more liable than carbon steels.—S. K.

The Construction of Moulds for Steel Works. H. Uhlitzsch. (*Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin*, 1956, 91–126). Mould dimension is the most important factor governing the life of steel works moulds. Methods of evaluating and calculating suitable mould dimensions are given. Good agreement is reported between calculated values and experimental results. (25 references.)—R. P.

On the Manufacture of Rimmed Steel in a Small Ingot Mould. M. Kamiya. (*Tetsu to Hagane*, 1957, **43**, Mar., 288). [In Japanese].

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The Behaviour of Sulphur in the Open Hearth Furnace. L. Prešeren. (*Nova Proizvodnja*, 1954, **5**, (3–4), 193–200). Sulphur balances are worked out for over 60 charges and compositions at various stages of the process are given. Equilibrium constants are evaluated and conditions for desulphurization are defined, and the amount of lime needed and time taken discussed. Coal with a maximum of 0·7% S is regarded as essential for refining in normal periods.

The Separation of the Degassing Process from the Gassing Process of Steels in Open-Hearth Furnaces. J. A. Verö. (*Neue Hütte*, 1957, **2**, Oct., 605–606). An alteration in the H_2 content of open-hearth steel during the heat comprises degassing and gassing. Degassing is due to CO bubbles and can be calculated from the carbon loss and the original H_2 content approximately at the time of fusion. The rate of gassing can also be determined by this means: it amounts to about 1·5 to 3 ml per 100 g per h.—L. J. L.

Reconstruction of Open Hearth Furnaces at the Red October Plant in Stalingrad. G. A. Sokolov. (*Metallurg*, 1957, (9), 11–14). The author recounts briefly the history of O.H. furnace construction at Stalingrad since 1897 and describes how these furnaces have been redesigned.—R. S.

Blowing Out the Dust From the Bottom of Open Hearth Checkers. V. N. Kazantsev. (*Metallurg*, 1957, (9), 14–16). This article describes the use of steam lancing to clean out the bottom of the checkers at the Kuznetsk plant in Siberia. Two Laval nozzles are used.

Experience with the 500-Ton Open Hearth Furnace in Russia. G. A. Garbuz, M. P. Sabiev and E. A. Ploshchenko. (*Stal'*, 1957, (11), 976–982). The working of the 500-t O.H. furnace at Voroshilovsk Plant, Alchevsk is described. Dimensions are given and various faults found in the installation are noted and changes made at the first shut down (after 381 heats, for repairing the casting crane) are described. Charge composition and particulars of melt down with the time of each operation are given. Thermal conditions in the furnace are indicated.—R. S.

Study of the Control and Regulation of Open Hearth Furnaces. R. Alleyrac, R. Ferry, L. Septier, H. Chan, and M. Faure. (*Pub. Inst. Rech. Sid.*, 1957, Series **A**, No. 167, Aug., 127 pp.) A comprehensive review of O.H. practice in France is presented. Particular attention is paid to the techniques employed in controlling the steelmaking process; these include factors influencing productivity and quality. A detailed study has been made at two works. The results obtained are reproduced in a series of appendixes in full. Speed of melting, factors limiting heat input and rate of decarburization are the main variables covered.—B. G. B.

Study of the Control and Regulation of Open Hearth Furnaces. R. Alleyrac, C. Hoang, and L. Septier. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 7, 1465–1499). The results of a detailed study of O.H. instrumentation and methods of increasing furnace productivity by its use are presented. Operation at two plants is discussed and full details of practice is given.—B. G. B.

Design, Control Gear and Operational Results of a Two-Stack Open-Hearth Furnace. E. Goebel and H. Leopold. (*Stahl u. Eisen*, 1957, **77**, Nov. 28, 1733–1739). The authors describe an O.H. furnace of 150-t capacity built for the Phoenix-Rheinrohr AG. by Maerz-Ofenbau G.m.b.H. A rather unusual design was developed as the space for the furnace was very restricted. The difference from the American-type of design of two-stack furnaces is the employment of direct acting blowers, using variable-pitch propellers. Design, control gear, and the results of the first two campaigns are described in detail. The furnace has a high efficiency and a low heat consumption.—T. G.

Methods of Increasing the Productivity of Open Hearth Furnaces. Ya. A. Shneerov and A. G. Kotin. (*Metallurg*, 167, (8), 18–20). This article refers to a fundamental study in 1955–56 of measures to increase the productivity of O.H. furnaces at seven Soviet plants. The main features of their work are reviewed. Full details were published in the Russian book "Large Open Hearth Furnaces" by Shneerov (*Metallurgizdat*, 1956).—R. S.

New Method of Lining the Hearth of Basic Open Hearth Furnaces. M. S. Sokolov and P. P. Semenenko. (*Metallurg*, 1957, (8), 23–26). Russian experience in burning in basic hearths with mixtures of magnesite powder and millscale is reviewed. Millscale was used only for diminishing the harmful effect of the reducing gases on the magnesite lining.—R. S.

Russian Basic Roof Experience. R. Sewell. (*Iron Steel*, 1957, **30**, Aug., 389–391; Sept., 429–434). A review from the Russian literature of experience at several plants is given. Furnace construction, brick compositions, and cold repair times are noted. The Chelyabinsk and Red October plants are then described and roof construction and service reviewed. Conclusions and recommendations are then given and the improvements produced are listed.

Slag Pockets. Results Obtained at Marpent During Recent Campaigns. H. Potvin. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 8, 1647–1649). Recent results obtained at this French plant on slag pocket design of a 35 ton furnace are described.—B. G. B.

Slag Scrubs Stainless. (*Steel*, 1957, **141**, Sept. 30, 86). A method developed and used at Eastern Stainless Steel Corp. for slag-washing Ti-bearing stainless steel is described. The technique is designed to produce steel free from stringer type inclusions, banding, or segregation of Ti. The steel is used for aircraft parts and polished sheets.—D. L. C. P.

Thermal Conditions of Open Hearth Heats with Oxygen Injection of the Bath. V. T. Sladkoshteev and G. A. Podol'skaya. (*Metallurg*, 1957, (8), 21–22). Optimum conditions for blowing the bath with oxygen were established on the basis of experiments in 350-t furnaces at Azovstal. Injection of O_2 into the flame and the bath is compared with the lancing of the bath only. The effect on roof and checker temperatures is reviewed. Details of waste gas analysis are reported.

Production of Chromium Structural Steel in a 380-Ton Open Hearth Furnace. B. G. Petukhov. (*Metallurg*, 1957, (3), 11–14). The charge for producing straight chromium steels in large furnaces consists of 62–68% hot metal, 32–38% steel scrap, 10·6–12·3% iron ore and 4·2–5·9% limestone. Details of the heat are reported. The use of 380-t furnaces instead of 190-t furnaces increased the monthly production of Cr steels by 1800–1900 t.—R. S.

Regenerators. W. Trinks. (*Ind. Heat.*, 1957, **24**, Sept., 1768, 1770). A note marking the centenary and suggesting improvements in view of the great loss of heat by radiation.

Theory on the Production of High-Quality Killed Steel. H. Schenck. (*Stahl u. Eisen*, 1957, **77**, Oct. 17, 1442–1450; discussion and corrigendum, Nov. 14, 1698–1699). The reactions involved in the slagging of steel melts are discussed in terms of physico-chemical efficiency and slag quantity. The effect of repeated, complete and incomplete changes of the slag are described. High-oxygen content of the charge may be useful for removal of accompanying elements, hydrogen, and non-metallic suspensions. There is, however, a risk that the charge may be oxidized from the slag at a later stage of refining.—T. G.

Studies on the Iron (II) Oxide–Manganese (II) Oxide Phase Diagram and its Relation to the Deoxidation of Pure Iron with Manganese. H. Schenck, N. G. Schmahl, and A. K. Biswas. (*Arch. Eisenhütten.*, 1957, **28**, Sept., 517–521). The phase diagram of the FeO–MnO system has been determined afresh by direct observation of incipient and complete melting of small cylinders of mixtures heated in a novel Mo coil furnace.—L. J. L.

Oxidation of Liquid Steel During and After Tapping from an Open-Hearth Furnace. N. S. Mikhailets. (*Stal'*, 1956, **16**, (3), 214–216). Experiments on rimming steels where agitation is sufficient to give uniformity for sampling showed losses of Mn outside the furnace to average 0·12%. With killed steels there is little agitation but Mn loss could sometimes be computed. For 6 heats of 18KhGT steel (0·8–1·1% Mn, 0·16–0·24% C) with 28–41 min between addition of Si–Mn and sampling, total loss was 0·24%, 0·11% outside the furnace. Most loss appears to be due to air entrained in pouring. Taphole conditions should be carefully watched; also reduced oxidation loss cuts down the number of inclusions.

The Duplex Process Bessemer–Open Hearth. Devernay. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 8, 1641–1645). The results are given of a survey of the conditions which make the Duplex process an economic proposition.—B. G. B.

Electric Iron and Steel Production. H. Walde and B. Marincek. (*Elektrowärme*, 1957, **15**, Oct., 355–360). Processes using electric heating to economise coke are discussed. The electric low-shaft furnace is reviewed and its development to a capacity of > 500 t/day. Dust emission is reduced and automation simplified and with lower initial costs the electric smelting process is particularly well suited to small or medium sized works where power is rela-

tively cheap. Data for cost comparison are given.

The Largest Arc Furnace in Europe. (*Techn. Human.*, 1956–57, **54**, (3), 147–148). The largest furnace has been used for some months at Charleroi, Belgium. It is 730 cm in dia. and has a nominal capacity of 150 metric tonnes of steel which should produce 15,000 per month. Details of the transformer system and current consumption (41250 amp) are mentioned.

Steelmaking Practice for Large Arc Furnaces. F. T. Bagnall. (*Iron Coal Trades Rev.*, 1957, **175**, Dec. 6, 1325–1328). The step from 10-t to 60-t arc furnaces for alloy steel making is described. A double-slag process is used and stirring, refractories, and costs are briefly indicated. In discussion, the use of the stirrer, the wear of refractories and chromium recovery were considered.

Faults in the Design of DCB-type Arc Furnaces. M. G. Dmitrienko and A. I. Sapko. (*Stal'*, 1957, (10), 902–904). The present design and suggested improvements are shown. A roll out trolley should be fitted and the hydraulic drives require improvement. The large furnaces should have swinging roofs.

Mechanisation of the Heavy Operations Associated with Electric Furnaces. G. Borodulin. (*Stal'*, 1957, (10), 912–914). A flux-throwing machine and a water-cooled oxygen lance are described and also a machine for fettling arc furnaces.—R. S.

Technical and Economic Indices of Electric Melting Operations. V. G. Speranskii. (*Stal'*, 1957, (10), 909–912). The growing importance of electric arc furnaces in Russian production of special steels is discussed with a review of the last 25 years. Details are given of tap to tap time, charged weights, transformer power per ton of steel, down time for major repairs, electrode consumption and ingot mould consumption, refractories, economics, and steel defects. Details of the life of magnesite-chrome and silica roofs are tabulated for stainless and alloy steels in 20-t furnaces.—R. S.

New Results Obtained in Studying Temperature Variations in Electric Furnaces as a Function of Time and Power Input. J. Bréfort. (*Chaleur et Ind.*, 1957, **38**, April, 85–94). A brief introduction discussing the differential equation for evaluating the temperature in electric furnaces is followed by a description of the experimental arrangement used. Results for power input of 33·5 W to 40 kW are discussed. Further work is suggested.

Production of Ball Bearing Steel in Large Arc Furnaces. V. M. Sevest'yanov. (*Metallurg*, 1957, (10), 9–10). Russian ball bearing steels are mostly produced in 40-t arc furnaces with magnesite chrome roofs. Oxygen is used and the metal is deoxidized with coke (deoxidation period is 40 min). Details of slag control are given. The quality of steel was not affected by the size of the furnace within the range of 20 to 40 t capacity.—R. S.

Direct-Arc Steel-Melting Furnace. (*Overseas Eng.*, 1957, **31**, Nov., 130–131). An account of the 20-ft dia. hearth arc furnace installed by Samuel Fox and Co. at Stockbridge.

Sintered Magnesite Hearth Linings for Electric Furnaces. (*Fonderia*, 1957, **6**, July, 335). [In Italian]. A brief account is given of the means of preparing magnesite for electric furnace hearth linings. The procedure to be followed to ensure satisfactory sintering of the magnesite is described.—M. D. J. B.

20MVA Transformer for Arc Furnaces. (*Engineer*, 1957, **204**, Oct. 25, 606–607). A furnace with a 20-ft hearth and a capacity of 80-t is mentioned, for producing 1400–1600 t stainless and alloy steels weekly. The transformer, working directly from a 66 kV supply, is described.

Fire Resistant Hydraulic Fluids for Near-Furnace Systems Safeguard Life and Property at No Loss of Efficiency. C. R. Schmitt. (*Ind. Heat.*, 1957, **24**, Sept., 1756, 1758, 1760, 1762, 1764, 1766, 1770). Fluids for electric furnace tilting mechanisms and similar hydraulic gear are reviewed. Tests are mentioned and types are outlined.

Research in the Development of New Grades of Steel and Alloys, Metallurgy, and Heat Treatment. M. V. Pridantsev. (*Stal'*, 1957, (11), 1006–1010).

A.I.S.I. Standard Alloy Steel Compositions. (*Metal Progress*, 1957, **72**, Aug., 96B). A list of the chemical analysis of over 200 A.I.S.I. standard O.H. and electric furnace alloy steels is given.—B. G. B.

New Grades of Low Alloy Steels. M. V. Pridantsev and G. L. Livshits. (*Metallurg*, 1957, (7), 18–19). The disadvantages of weldable high tensile low alloy steels compared with plain carbon steels are reviewed. Russian specifications for these steels usually stipulate a lower carbon content than British and American standards. Special care must be taken with deoxidation. The Al addition was 0·55 lb/t followed by an addition of 2 to 5·5 lb/t of Ti depending on the grade of steel and the thickness of the rolled product. Mn is added only in the ladle (no SiMn was used for preliminary deoxidation). Highly carbonaceous exothermic feeder head mixtures are not used.—R. S.

Composition, Properties and Strength Data of American Metallic Materials for Coiled Compression Springs. H. Keitel. (*Draht*, 1957, **8**, May, 180–186). Particulars are given of straight carbon, low and high alloy steels, and copper and nickel alloys commonly employed in America for the manufacture of coiled compression springs from wire. The data quoted include permissible stress levels, elastic constants, density, hardness, permanent set at elevated temperatures, and the Vickers hardness as a function of cold working by drawing.—J. G. W.

Canadian Landing Gear Uses 260000 [p.s.i.] Tensile Steel. G. F. W. McCaffrey. (*Can. Metalw.*, 1957, **20**, Oct., 8–10, 12). The development of Dowcan 110 steel and its properties, fabrication, and uses is outlined.

Trends in Metals: Stainless Steels. (*Steel*, 1957, **141**, Nov. 4, 107–122). A table of producers and trends in development is given and a survey of user's requirements, a review of uses, and an account of fabrication processes with a table of steel compositions are shown, based on questionnaires.

Optimum Chemical Composition of Russian 1Kh18N9T Stainless Steel. M. I. Vinograd. (*Metallurg*, 1957, (5), 13–16). Data were obtained from more than 500 heats to ascertain the effect of elements on the amount of α-phase and intergranular corrosion. The importance of the Ti–C ratio is emphasized.—R. S.

New Method of Producing Stainless Steel. B. A. Shilyaev. (*Metallurg*, 1957, (7), 20–21). Advantages of using O_2 in 20-, 30-, and 40-t arc furnaces are discussed. Variations in methods at four Russian steel plants are described.—R. S.

A New Stainless for Atomic Energy. J. A. Berger and W. L. Keene. (*Steel*, 1957, **141**, Sept. 9, 104–107). Production, properties, and applications of 1% and 2% B stainless steels are described. The 1% type is being used as a thermal shield in atomic reactors; the 2% type for control rods.—D. L. C. P.

High Tensile Stainless: New Firth-Vickers Steel. (*Iron Steel*, 1957, **30**, Oct., 487–488). The new steel FV520 developed by Firth-Vickers Ltd. combines the high strength and relatively low thermal expansion of 2S80 with the corrosion resistance of 18/8. Its composition is 0·07% C, 1·0% Si max., 2·0% Mn max., 14–18% Cr, 4–7% Ni, 1–3% Cu, 1–3% Mo, 0·5% Ti max. Details are given of its mechanical and hot tensile properties, weldability, dimensional changes during heat treatment, and the effect of cold work on the response to heat treatment.—G. F.

New Steel for Hot Aircraft. (*Steel*, 1957, **141**, Sept. 23, 138–139). A steel has been developed by Armco Steel Corp. for use in aircraft at up to 1000° F; it is called "PH 15-7 Mo." Its cost is one-tenth that of high strength Ti alloys and it is the easiest of high strength alloys to form. It contains 15% Cr and 7% Ni; high strength properties come from a strong precipitation hardening reaction fostered by 1·2% Al; about 2·5% Mo is used to secure good retention of high strength properties; carbon is below 0·09%. Properties are specified; procedures for hardening can be varied to suit different production situations.

Production of Chromium-Nickel Steel Using Pelletised Nickel Oxide. I. P. Zabaluev, T. M. Bobkov, and N. T. Tarashchuk. (*Stal'*, 1957, (10), 899–901). Pelletised nickel oxide is satisfactory for alloy steel production supplying 98% of the Ni required by adding during charging or to the slag during the oxidising period. H_2 is not increased, nor is power consumption.—R. S.

The Quality of 08KP Steel Produced by Oxygen Injection. A. A. Mitrofanov, N. P. Cherkashina, and N. A. Volkova. (*Stal'*, 1957, (10), 888–892). Yield and quality were improved by O_2 blowing.

Production of Non-Ageing Steel. I. S. Marakhovskii and A. A. Podgorodetskii. (*Metallurg*, 1957, (5), 11–13). Low carbon non-ageing steel is produced at Zaporozhstal in 200-t O.H. furnaces fired with mixed coke oven and blast furnace gas. Up to 25% O_2 is used during charging and melt-down to enrich the flame. Fe–V was added to the ladle to achieve a V content of 0·03–0·05% in the finished steel. In another trial heat, Al was added to the ladle so as to produce 0·05–0·07% Al in the steel. It was found that the V steel was more ductile than the Al steel. The Gorki automobile plant has now specified these V steels for deep drawing.—R. S.

The Melting of Transformer Steel. K. Fellcht and H. Kutscher. (*Neue Hütte*, 1957, **2**, Sept., 525–537). A systematic investigation of the factors that influence the magnetic reversal losses of transformer plate showed that, to keep these losses to a minimum, the silicon content must be high, the carbon content low, and non-metallic impurities must be reduced. Freedom from absorbed or dissolved gases, and from the resulting internal stresses, are even more important.—L. J. L.

Production of Transformer Steel. V. A. Lakhne. (*Metallurg*, 1957, (10), 11–12). This brief article gives some details of a production heat. SiCa is used for deoxidation.—R. S.

More Jobs Open for Rare Earth Additives. (*Steel*, 1957, **141**, Sept. 9, 112–115). The use of rare earth additions for the following purposes are described, with examples: improvement of ductility and strength, tramp element control, grain refinement, deoxidation, scale suppression.—D. L. C. P.

Rare Earth Metals: Their Properties and Industrial Application. F. Trombe. (*Met. Treatment*, 1957, **24**, Oct., 421–424). Uses in steelmaking and in stainless steels are mentioned.

Thin Walled Ingot Moulds for the Production of Killed Steels. A. M. Danilov. (*Metallurg*, 1957, (6), 19–20). In view of conflicting opinions regarding the effect of mould wall thickness on the structure and quality of alloy steel, the Zlatoust plant carried out a systematic research on the question. O.H. alloy steel 3·6 t ingots were cast in moulds with wall thicknesses of 70 and 140 mm. No difference was observed in the structure of the ingots cast in the thin walled moulds and those cast in the moulds with thicker walls. The thin walled moulds had a slightly longer life due to more even wear.—R. S.

Lightweight Design of Steelworks Ladles. M. E. Krivitskii and G. A. Dubrovin. (*Metallurg*, 1957, (9), 18–20). Due to increasing steel output, the 180- and 200-t ladles at Zaporozhstal (Ukraine) had to be redesigned. It was not possible to increase the weight of these ladles beyond a certain limit and, therefore, a special, lightweight, all-welded, 220-t ladle with a tare of 15·8% was designed. There was a redistribution of stress in the thinner ladle elements. After 7 to 8 casts, ladle capacity is increased to 225 tons.—R. S.

The Casting of Steel in a Protective Nitrogen Atmosphere. P. Holtzhaussen and H. Fiedler. (*Neue Hütte*, 1957, **2**, Nov., 685–691). 3·5-t ingots of X10CrAl7 steel have been cast in a N_2 atmosphere at the Karl Marx Stadt Steel Works since 1954. Operating experience at this and other steel works is reported.—L. J. L.

Basic Phenomena Occurring in the Process of Solidification of Castings and Ingots. J. Přibyl. (*Sborník Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1956, **2**, (4), 29–52). [In Czech]. The major problems encountered, such as the formation of shrinkage cavities,

Properties of Cast Alloy Structural Steel. B. B. Gulyaev, I. A. Shapranov, V. M. Shpeizman, and P. E. Kovalenko. (*Liteinoe Proizvodstvo*, 1957, (2), 11–16). [In Russian]. The results are presented of a comparative investigation of the mechanical and technological properties of some of the main types of cast structural steels alloyed to different degrees and of one carbon steel. The steels were melted in 0·5 and 3·0-t electric furnaces and cast into bars with wall-thickness varying from 12–100 mm from which the mechanical test-pieces were cut. The bars were subjected to annealing or normalization in preliminary treatment at 860–900° C for 2, 4 or 5 hr, to normalization and hardening at 850–880° C for 2, 3 or 4 hr and tempering for 3, 4 or 5 hr at 640–680° C. Plots of the Brinell hardness, toughness, relative elongation and contraction, the yield-point and ultimate strengths against tempering temperature and wall thickness after normalization and after hardening are shown. The results show that the use of alloy instead of carbon steels enables casting strength to be increased appreciably without loss of plasticity. Hardenability tests were also carried out, the plot of the results showing that the alloy steels differ somewhat among themselves and all have a higher hardenability than the carbon steel. The tendency to temper brittleness was found to differ little at ordinary temperatures, but great differences appeared at low temperatures. High-temperature mechanical tests and measurements of liquid steel fluidity were also carried out, several carbon steels being used for the latter. Other studies included hot cracking, to which, as confirmed by service tests, the alloy steels were found to be somewhat more liable than carbon steels.—S. K.

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Efficiency Considerations in the Operation of an Open-Hearth Steelworks and a Blooming Mill. H. Kallenbach. (*Stahl u. Eisen*, 1957, **77**, Nov. 14, 1667–1673). A statistical analysis based on the actual records of the works is presented, with recommendations of optimum operation efficiency.—T. G.

The Behaviour of Sulphur in the Open Hearth Furnace. L. Prešeren. (*Nova Proizvodnja*, 1954, **5**, (3–4), 193–200). Sulphur balances are worked out for over 60 charges and compositions at various stages of the process are given. Equilibrium constants are evaluated and conditions for desulphurization are defined, and the amount of lime needed and time taken discussed. Coal with a maximum of 0·7% S is regarded as essential for refining in normal periods.

The Separation of the Degassing Process from the Gassing Process of Steels in Open-Hearth Furnaces. J. A. Verö. (*Neue Hütte*, 1957, **2**, Oct., 605–606). An alteration in the H_2 content of open-hearth steel during the heat comprises degassing and gassing. Degassing is due to CO bubbles and can be calculated from the carbon loss and the original H_2 content approximately at the time of fusion. The rate of gassing can also be determined by this means: it amounts to about 1·5 to 3 ml per 100 g per h.—L. J. L.

Reconstruction of Open Hearth Furnaces at the Red October Plant in Stalingrad. G. A. Sokolov. (*Metallurg*, 1957, (9), 11–14). The author recounts briefly the history of O.H. furnace construction at Stalingrad since 1897 and describes how these furnaces have been redesigned.—B. S.

Blowing Out the Dust From the Bottom of Open Hearth Checkers. V. N. Kazantsev. (*Metallurg*, 1957, (9), 14–16). This article describes the use of steam lancing to clean out the bottom of the checkers at the Kuznetsk plant in Siberia. Two Laval nozzles are used.

Experience with the 500-Ton Open Hearth Furnace in Russia. G. A. Garbuz, M. P. Sabiev and E. A. Ploshchenko. (*Stal'*, 1957, (11), 976–982). The working of the 500-t O.H. furnace at Voroshilovsk Plant, Alchevsk is described. Dimensions are given and various faults found in the installation are noted and changes made at the first shut down (after 381 heats, for repairing the casting crane) are described. Charge composition and particulars of melt down with the time of each operation are given. Thermal conditions in the furnace are indicated.—B. S.

Study of the Control and Regulation of Open Hearth Furnaces. R. Alleyrac, R. Ferry, L. Septier, H. Chan, and M. Faure. (*Pub. Inst. Rech. Sid.*, 1957, Series **A**, No. 167, Aug., 127 pp.) A comprehensive review of O.H. practice in France is presented. Particular attention is paid to the techniques employed in controlling the steelmaking process; these include factors influencing productivity and quality. A detailed study has been made at two works. The results obtained are reproduced in a series of appendixes in full. Speed of melting, factors limiting heat input and rate of decarburization are the main variables covered.—B. G. B.

Study of the Control and Regulation of Open Hearth Furnaces. R. Alleyrac, C. Hoang, and L. Septier. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 7, 1465–1499). The results of a detailed study of O.H. instrumentation and methods of increasing furnace productivity by its use are presented. Operation at two plants is discussed and full details of practice is given.—B. G. B.

Design, Control Gear and Operational Results of a Two-Stack Open-Hearth Furnace. E. Goebel and H. Leopold. (*Stahl u. Eisen*, 1957, **77**, Nov. 28, 1733–1739). The authors describe an O.H. furnace of 150-t capacity built for the Phoenix-Rheinrohr AG. by Maerz-Ofenbau G.m.b.H. A rather unusual design was developed as the space for the furnace was very restricted. The difference from the American-type of design of two-stack furnaces is the employment of direct acting blowers, using variable-pitch propellers. Design, control gear, and the results of the first two campaigns are described in detail. The furnace has a high efficiency and a low heat consumption.—T. G.

Methods of Increasing the Productivity of Open Hearth Furnaces. Ya. A. Shneerov and A. G. Kotin. (*Metallurg*, 167, (8), 18–20). This article refers to a fundamental study in 1955–56 of measures to increase the productivity of O.H. furnaces at seven Soviet plants. The main features of their work are reviewed. Full details were published in the Russian book "Large Open Hearth Furnaces" by Shneerov (*Metallurgizdat*, 1956).—B. S.

New Method of Lining the Hearth of Basic Open Hearth Furnaces. M. S. Sokolov and P. P. Semenenko. (*Metallurg*, 1957, (8), 23–26). Russian experience in burning in basic hearths with mixtures of magnesite powder and millscale is reviewed. Millscale was used only for diminishing the harmful effect of the reducing gases on the magnesite lining.—B. S.

Russian Basic Roof Experience. R. Sewell. (*Iron Steel*, 1957, **30**, Aug., 389–391; Sept., 429–434). A review from the Russian literature of experience at several plants is given. Furnace construction, brick compositions, and cold repair times are noted. The Chelyabinsk and Red October plants are then described and roof construction and service reviewed. Conclusions and recommendations are then given and the improvements produced are listed.

Slag Pockets. Results Obtained at Marpent During Recent Campaigns. H. Potvin. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 8, 1647–1649). Recent results obtained at this French plant on slag pocket design of a 35 ton furnace are described.—B. G. B.

Slag Scrubs Stainless. (*Steel*, 1957, **141**, Sept. 30, 86). A method developed and used at Eastern Stainless Steel Corp. for slag-washing Ti-bearing stainless steel is described. The technique is designed to produce steel free from stringer type inclusions, banding, or segregation of Ti. The steel is used for aircraft parts and polished sheets.—D. L. C. P.

Thermal Conditions of Open Hearth Heats with Oxygen Injection of the Bath. V. T. Sladkoshteev and G. A. Podol'skaya. (*Metallurg*, 1957, (8), 21–22). Optimum conditions for blowing the bath with oxygen were established on the basis of experiments in 350-t furnaces at Azovstal. Injection of O_2 into the flame and the bath is compared with the lancing of the bath only. The effect on roof and checker temperatures is reviewed. Details of waste gas analysis are reported.

Production of Chromium Structural Steel in a 380-Ton Open Hearth Furnace. B. G. Petukhov. (*Metallurg*, 1957, (3), 11–14). The charge for producing straight chromium steels in large furnaces consists of 62–68% hot metal, 32–38% steel scrap, 10·6–12·3% iron ore and 4·2–5·9% limestone. Details of the heat are reported. The use of 380-t furnaces instead of 190-t furnaces increased the monthly production of Cr steels by 1800–1900 t.—B. S.

Regenerators. W. Trinks. (*Ind. Heat.*, 1957, **24**, Sept., 1768, 1770). A note marking the centenary and suggesting improvements in view of the great loss of heat by radiation.

Theory on the Production of High-Quality Killed Steel. H. Schenck. (*Stahl u. Eisen*, 1957, **77**, Oct. 17, 1442–1450; discussion and corrigendum, Nov. 14, 1698–1699). The reactions involved in the slagging of steel melts are discussed in terms of physico-chemical efficiency and slag quantity. The effect of repeated, complete and incomplete changes of the slag are described. High-oxygen content of the charge may be useful for removal of accompanying elements, hydrogen, and non-metallic suspensions. There is, however, a risk that the charge may be oxidized from the slag at a later stage of refining.—T. G.

Studies on the Iron (II) Oxide–Manganese (II) Oxide Phase Diagram and its Relation to the Deoxidation of Pure Iron with Manganese. H. Schenck, N. G. Schmahl, and A. K. Biswas. (*Arch. Eisenhütten.*, 1957, **28**, Sept., 517–521). The phase diagram of the FeO–MnO system has been determined afresh by direct observation of incipient and complete melting of small cylinders of mixtures heated in a novel Mo coil furnace.—L. J. L.

Oxidation of Liquid Steel During and After Tapping from an Open-Hearth Furnace. N. S. Mikhailets. (*Stal'*, 1956, **16**, (3), 214–216). Experiments on rimming steels where agitation is sufficient to give uniformity for sampling showed losses of Mn outside the furnace to average 0·12%. With killed steels there is little agitation but Mn loss could sometimes be computed. For 6 heats of 18KhGT steel (0·8–1·1% Mn, 0·16–0·24% C) with 28–41 min between addition of Si–Mn and sampling, total loss was 0·24%, 0·11% outside the furnace. Most loss appears to be due to air entrained in pouring. Taphole conditions should be carefully watched; also reduced oxidation loss cuts down the number of inclusions.

The Duplex Process Bessemer–Open Hearth. Devernay. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, No. 8, 1641–1645). The results are given of a survey of the conditions which make the Duplex process an economic proposition.—B. G. B.

Electric Iron and Steel Production. H. Walde and B. Marincek. (*Elektrowärme*, 1957, **15**, Oct., 355–360). Processes using electric heating to economise coke are discussed. The electric low-shaft furnace is reviewed and its development to a capacity of > 500 t/day. Dust emission is reduced and automation simplified and with lower initial costs the electric smelting process is particularly well suited to small or medium sized works where power is rela-

tively cheap. Data for cost comparison are given.

The Largest Arc Furnace in Europe. (*Techn. Human.*, 1956–57, **54**, (3), 147–148). The largest furnace has been used for some months at Charleroi, Belgium. It is 730 cm in dia. and has a nominal capacity of 150 metric tonnes of steel which should produce 15,000 per month. Details of the transformer system and current consumption (41250 amp) are mentioned.

Steelmaking Practice for Large Arc Furnaces. F. T. Bagnall. (*Iron Coal Trades Rev.*, 1957, **175**, Dec. 6, 1325–1328). The step from 10-t to 60-t arc furnaces for alloy steel making is described. A double-slag process is used and stirring, refractories, and costs are briefly indicated. In discussion, the use of the stirrer, the wear of refractories and chromium recovery were considered.

Faults in the Design of DCB-type Arc Furnaces. M. G. Dmitrienko and A. I. Sapko. (*Stal'*, 1957, (10), 902–904). The present design and suggested improvements are shown. A roll out trolley should be fitted and the hydraulic drives require improvement. The large furnaces should have swinging roofs.

Mechanisation of the Heavy Operations Associated with Electric Furnaces. G. Borodulin. (*Stal'*, 1957, (10), 912–914). A flux-throwing machine and a water-cooled oxygen lance are described and also a machine for fettling arc furnaces.—R. S.

Technical and Economic Indices of Electric Melting Operations. V. G. Speranskii. (*Stal'*, 1957, (10), 909–912). The growing importance of electric arc furnaces in Russian production of special steels is discussed with a review of the last 25 years. Details are given of tap to tap time, charged weights, transformer power per ton of steel, down time for major repairs, electrode consumption and ingot mould consumption, refractories, economics, and steel defects. Details of the life of magnesite-chrome and silica roofs are tabulated for stainless and alloy steels in 20-t furnaces.—R. S.

New Results Obtained in Studying Temperature Variations in Electric Furnaces as a Function of Time and Power Input. J. Bréfort. (*Chaleur et Ind.*, 1957, **38**, April, 85–94). A brief introduction discussing the differential equation for evaluating the temperature in electric furnaces is followed by a description of the experimental arrangement used. Results for power input of 33·5 W to 40 kW are discussed. Further work is suggested.

Production of Ball Bearing Steel in Large Arc Furnaces. V. M. Sevest'yanov. (*Metallurg*, 1957, (10), 9–10). Russian ball bearing steels are mostly produced in 40-t arc furnaces with magnesite chrome roofs. Oxygen is used and the metal is deoxidized with coke (deoxidation period is 40 min). Details of slag control are given. The quality of steel was not affected by the size of the furnace within the range of 20 to 40 t capacity.—R. S.

Direct-Arc Steel-Melting Furnace. (*Overseas Eng.*, 1957, **31**, Nov., 130–131). An account of the 20-ft dia. hearth arc furnace installed by Samuel Fox and Co. at Stockbridge.

Sintered Magnesite Hearth Linings for Electric Furnaces. (*Fonderia*, 1957, **6**, July, 335). [In Italian]. A brief account is given of the means of preparing magnesite for electric furnace hearth linings. The procedure to be followed to ensure satisfactory sintering of the magnesite is described.—M. D. J. B.

20MVA Transformer for Arc Furnaces. (*Engineer*, 1957, **204**, Oct. 25, 606–607). A furnace with a 20-ft hearth and a capacity of 80-t is mentioned, for producing 1400–1600 t stainless and alloy steels weekly. The transformer, working directly from a 66 kV supply, is described.

Fire Resistant Hydraulic Fluids for Near-Furnace Systems Safeguard Life and Property at No Loss of Efficiency. C. R. Schmitt. (*Ind. Heat.*, 1957, **24**, Sept., 1756, 1758, 1760, 1762, 1764, 1766, 1770). Fluids for electric furnace tilting mechanisms and similar hydraulic gear are reviewed. Tests are mentioned and types are outlined.

Research in the Development of New Grades of Steel and Alloys, Metallurgy, and Heat Treatment. M. V. Pridantsev. (*Stal'*, 1957, (11), 1006–1010).

A.I.S.I. Standard Alloy Steel Compositions. (*Metal Progress*, 1957, **72**, Aug., 96B). A list of the chemical analysis of over 200 A.I.S.I. standard O.H. and electric furnace alloy steels is given.—B. G. B.

New Grades of Low Alloy Steels. M. V. Pridantsev and G. L. Livshits. (*Metallurg*, 1957, (7), 18–19). The disadvantages of weldable high tensile low alloy steels compared with plain carbon steels are reviewed. Russian specifications for these steels usually stipulate a lower carbon content than British and American standards. Special care must be taken with deoxidation. The Al addition was 0·55 lb/t followed by an addition of 2 to 5·5 lb/t of Ti depending on the grade of steel and the thickness of the rolled product. Mn is added only in the ladle (no SiMn was used for preliminary deoxidation). Highly carbonaceous exothermic feeder head mixtures are not used.—R. S.

Composition, Properties and Strength Data of American Metallic Materials for Coiled Compression Springs. H. Keitel. (*Draht*, 1957, **8**, May, 180–186). Particulars are given of straight carbon, low and high alloy steels, and copper and nickel alloys commonly employed in America for the manufacture of coiled compression springs from wire. The data quoted include permissible stress levels, elastic constants, density, hardness, permanent set at elevated temperatures, and the Vickers hardness as a function of cold working by drawing.—J. G. W.

Canadian Landing Gear Uses 260000 [p.s.i.] Tensile Steel. G. F. W. McCaffrey. (*Can. Metalw.*, 1957, **20**, Oct., 8–10, 12). The development of Dowcan 110 steel and its properties, fabrication, and uses is outlined.

Trends in Metals: Stainless Steels. (*Steel*, 1957, **141**, Nov. 4, 107–122). A table of producers and trends in development is given and a survey of user's requirements, a review of uses, and an account of fabrication processes with a table of steel compositions are shown, based on questionnaires.

Optimum Chemical Composition of Russian 1Kh18N9T Stainless Steel. M. I. Vinograd. (*Metallurg*, 1957, (5), 13–16). Data were obtained from more than 500 heats to ascertain the effect of elements on the amount of α-phase and intergranular corrosion. The importance of the Ti–C ratio is emphasized.—R. S.

New Method of Producing Stainless Steel. B. A. Shilyaev. (*Metallurg*, 1957, (7), 20–21). Advantages of using O_2 in 20-, 30-, and 40-t arc furnaces are discussed. Variations in methods at four Russian steel plants are described.—R. S.

A New Stainless for Atomic Energy. J. A. Berger and W. L. Keene. (*Steel*, 1957, **141**, Sept. 9, 104–107). Production, properties, and applications of 1% and 2% B stainless steels are described. The 1% type is being used as a thermal shield in atomic reactors; the 2% type for control rods.—D. L. C. F.

High Tensile Stainless: New Firth-Vickers Steel. (*Iron Steel*, 1957, **30**, Oct., 487–488). The new steel FV520 developed by Firth-Vickers Ltd. combines the high strength and relatively low thermal expansion of 2S80 with the corrosion resistance of 18/8. Its composition is 0·07% C, 1·0% Si max., 2·0% Mn max., 14–18% Cr, 4–7% Ni, 1–3% Cu, 1–3% Mo, 0·5% Ti max. Details are given of its mechanical and hot tensile properties, weldability, dimensional changes during heat treatment, and the effect of cold work on the response to heat treatment.—G. F.

New Steel for Hot Aircraft. (*Steel*, 1957, **141**, Sept. 23, 138–139). A steel has been developed by Armco Steel Corp. for use in aircraft at up to 1000° F; it is called "PH 15-7 Mo." Its cost is one-tenth that of high strength Ti alloys and it is the easiest of high strength alloys to form. It contains 15% Cr and 7% Ni; high strength properties come from a strong precipitation hardening reaction fostered by 1·2% Al; about 2·5% Mo is used to secure good retention of high strength properties; carbon is below 0·09%. Properties are specified; procedures for hardening can be varied to suit different production situations.

Production of Chromium-Nickel Steel Using Pelletised Nickel Oxide. I. P. Zabaluev, T. M. Bobkov, and N. T. Tarashchuk. (*Stal'*, 1957, (10), 899–901). Pelletised nickel oxide is satisfactory for alloy steel production supplying 98% of the Ni required by adding during charging or to the slag during the oxidising period. H_2 is not increased, nor is power consumption.—R. S.

The Quality of 08KP Steel Produced by Oxygen Injection. A. A. Mitrofanov, N. P. Cherkashina, and N. A. Volkova. (*Stal'*, 1957, (10), 888–892). Yield and quality were improved by O_2 blowing.

Production of Non-Ageing Steel. I. S. Marakhovskii and A. A. Podgorodetskii. (*Metallurg*, 1957, (5), 11–13). Low carbon non-ageing steel is produced at Zaporozhstal in 200-t O.H. furnaces fired with mixed coke oven and blast furnace gas. Up to 25% O_2 is used during charging and melt-down to enrich the flame. Fe–V was added to the ladle to achieve a V content of 0·03–0·05% in the finished steel. In another trial heat, Al was added to the ladle so as to produce 0·05–0·07% Al in the steel. It was found that the V steel was more ductile than the Al steel. The Gorki automobile plant has now specified these V steels for deep drawing.—R. S.

The Melting of Transformer Steel. K. Fellcht and H. Kutscher. (*Neue Hütte*, 1957, **2**, Sept., 525–537). A systematic investigation of the factors that influence the magnetic reversal losses of transformer plate showed that, to keep these losses to a minimum, the silicon content must be high, the carbon content low, and non-metallic impurities must be reduced. Freedom from absorbed or dissolved gases, and from the resulting internal stresses, are even more important.—L. J. L.

Production of Transformer Steel. V. A. Lakhne. (*Metallurg*, 1957, (10), 11–12). This brief article gives some details of a production heat. SiCa is used for deoxidation.—R. S.

More Jobs Open for Rare Earth Additives. (*Steel*, 1957, **141**, Sept. 9, 112–115). The use of rare earth additions for the following purposes are described, with examples: improvement of ductility and strength, tramp element control, grain refinement, deoxidation, scale suppression.—D. L. C. F.

Rare Earth Metals: Their Properties and Industrial Application. F. Trombe. (*Met. Treatment*, 1957, **24**, Oct., 421–424). Uses in steelmaking and in stainless steels are mentioned.

Thin Walled Ingot Moulds for the Production of Killed Steels. A. M. Danilov. (*Metallurg*, 1957, (6), 19–20). In view of conflicting opinions regarding the effect of mould wall thickness on the structure and quality of alloy steel, the Zlatoust plant carried out a systematic research on the question. O.H. alloy steel 3·6 t ingots were cast in moulds with wall thicknesses of 70 and 140 mm. No difference was observed in the structure of the ingots cast in the thin walled moulds and those cast in the moulds with thicker walls. The thin walled moulds had a slightly longer life due to more even wear.—R. S.

Lightweight Design of Steelworks Ladles. M. E. Krivitskii and G. A. Dubrovin. (*Metallurg*, 1957, (9), 18–20). Due to increasing steel output, the 180- and 200-t ladles at Zaporozhstal (Ukraine) had to be redesigned. It was not possible to increase the weight of these ladles beyond a certain limit and, therefore, a special, lightweight, all-welded, 220-t ladle with a tare of 15·8% was designed. There was a redistribution of stress in the thinner ladle elements. After 7 to 8 casts, ladle capacity is increased to 225 tons.—R. S.

The Casting of Steel in a Protective Nitrogen Atmosphere. P. Holtzhaussen and H. Fiedler. (*Neue Hütte*, 1957, **2**, Nov., 685–691). 3·5-t ingots of X10CrAl7 steel have been cast in a N_2 atmosphere at the Karl Marx Stadt Steel Works since 1954. Operating experience at this and other steel works is reported.—L. J. L.

Basic Phenomena Occurring in the Process of Solidification of Castings and Ingots. J. Přibyl. (*Sborník Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1956, **2**, (4), 29–52). [In Czech]. The major problems encountered, such as the formation of shrinkage cavities,

internal cracks and tears, dendritic, inverse and enhanced desegregation etc. are discussed and the most effective means of preventing such defects from occurring are considered in detail.—P. F.

Sources of Contamination of Steel with Oxide Inclusions during Casting and Teeming. E. I. Malinovskii and A. N. Morozov. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (8), 102–108). [In Russian]. In the investigation described, the nature of oxide inclusions in ball-bearing steel melted under industrial conditions was studied with the aid of radioactive isotopes of Ca,Zr and Ta. Results obtained show that: (1) the disruption products of ladle and bottom-pouring refractories do not remain in the finished steel, (2) the oxidation products, including high-melting inclusions, formed as a result of steel oxidation during casting, are sufficiently completely removed in the ladle; (3) contamination of steel with oxide inclusions occurs mainly through oxidation of strong deoxidizers during pouring and crystallization.

New Hot Top Cuts Ingot Discard In Half. W. Czygan. (*Iron Age*, 1957, **180**, Sept. 12, 123–126). A report on the use of the 'Vallak hot top' is given. The top is made up of cakes of crushed coke, or crushed coke and sawdust, with waste sulphite liquor as binder; after forming and drying, the cakes are coated on the inside face and lower edge with a refractory material. Its use has given considerable benefits in steel yield and quality and in cost; it is used in Swedish, German, and Japanese mills and is being tested in U.S.A.—D. L. C. P.

Hot Scarfing of Ingots. (*Fonderia*, 1957, **6**, July, 317–321). [In Italian]. This article describes the Innocenti automatic hot scarfing machine. Method of operation, production costs, and results obtained on the ingot are examined.—M. D. J. B.

The Deoxidation of Steel. A. D. Marsico. (*Tecn. Indust.*, 1957, **35**, Apr., 373–376). [In Spanish]. The principles of the deoxidation of liquid steel are discussed, and the principal characteristics of killed, semi-killed, and rimming steels are reviewed.—P. S.

Production of Killed Carbon Steel Without Preliminary Deoxidation in the Furnace. A. I. Borodulin. (*Metallurg*, 1957, (7), 16–17). Since January, 1956, high carbon and rail steels have been produced at Kuznetsk (Siberia) without preliminary deoxidation by FeSi. Trial heats were made in basic 190 and 380-t furnaces with and without deoxidation by FeSi. Mn losses were related to the duration of deoxidation which must not exceed 5 to 8 minutes. Deoxidation of rail steel by FeMn without FeSi increases Mn losses by 3·9% compared with the use of FeMn after FeSi and by 4% if the FeSi is added after the FeMn. When steel does not undergo preliminary deoxidation, the hydrogen and oxygen contents are reduced. Details of economies achieved by the new method of deoxidation are given.—R. S.

Deoxidation of Rimming Steel By Addition of Ferro-manganese in the Ladle. D. S. Gerchikov, A. M. Ofengenden, and L. M. Pokrass. (*Metallurg*, 1957, (6), 13–15). Rimming steel is produced at the Stalinsk (Siberia) plant in mixed gas fired, all-basic O.H. furnaces, charging 60–65% hot metal. The steel is uphill cast into 0·9 to 3·4 ton ingots. Data are reported on the variation in S and P contents and Mn losses with various methods of deoxidation. It was shown that, with deoxidation in the ladle, the metal temperature at tapping must not exceed that which is normal for deoxidation in the furnace (1600 to 1620° C). Deoxidation of rimming steel in the ladle by FeMn had no deleterious effects on metal quality. The only steels which are now deoxidized in the furnace are those high in sulphur. By deoxidation in the ladle, more than 600 tons of FeMn are saved each year.

Factors Affecting the Yield of Rimming Free-Cutting Steel. L. Heinen and A. Latour. (*Stahl u. Eisen*, 1957, **77**, Sept. 5, 1204–1209). The authors studied the relation between melting practice and yield of low-manganese, rimming, basic-Bessemer, free-cutting steel with particular reference to the oxygen content of the melt. They found that final blowing temperature, P and N levels, and iron content of the slag, all affect the yield. A separate chapter deals with the effects of Mn and S. The results, presented in a number of graphs, were applied to the mode of operation in Völklingen and improved the yield markedly.

Effect of Oxygen on Quality of Soft Rimming Steel. A. M. Pochtman. (*Metallurg*, 1957, (6), 15–16). Research on the amount of O_2 permissible in soft rimming steel showed that, as the O_2 content of the metal increased from 0·042–0·052 to 0·056–0·066%, the capacity for stamping after ageing was reduced. The minimum reduction in stamping capacity corresponded to 0·056–0·066% O_2 in the steel prior to deoxidation. Rising of the ingot in the mould increases as the O_2 content rises.—R. S.

Desulphurisation of Transformer Steel Outside the Furnace. D. D. Burdakov. (*Metallurg*, 1957, (2), 6–7). At Verkh-Isetsk in the Urals, transformer steel is produced in arc and basic arc furnaces. The latter are of 90 to 100 t capacity and are oil-fired. Details are given of the relationship between watt losses and the S content. A standardized process for producing silicon steel is detailed. At Verkh-Isetsk, a mixture of 80% of freshly burnt lime and 20% of ground fluorspar is added to the ladle during tapping. The amount of mixture consumed is 1·1 to 1·2% by weight of the metallic portion of the charge. About 30% of the mixture is placed in the ladle before tapping and 70% is added in the launder during tapping. All the mixture must be added to the metal before the slag leaves the furnace. This method reduced the S content of transformer steels from 0·0244 to 0·0117%.

Contamination of Ball Bearing Steel by Refining Slag. V. F. Smolyakov, E. S. Kalinnikov, and V. D. Potapov. (*'Stal'*, 1957, (10), 893–898). A method of determination was developed which confirmed the possibility of contamination by slag during tapping from a basic electric furnace. Slag inclusions in the rolled product, in some cases, reached 0·001% or about 1/10 of the total inclusions. There was a linear relationship between content of exogenic inclusions and the average numbers of defects due to oxides. When tapped under high-viscosity basic slag contamination was less than with fluid slags.—R. S.

The Use of Radioactive Calcium for the Study of Contamination of Steel by Refractory Particles During Pouring. O. M. Margulis and A. G. Karaulov. (*Ogneupory*, 1956, **21**, (6), 253–258). The activity was dispersed uniformly through the chamotte as $^{45}CaCl_2$ which was used for ladle linings. The amount of contamination in bottom pouring was found to be small, only 4·6% of the total non-metallic inclusions. When important dense kaolin or high-alumina bricks should be used in the linings. An editorial note points out other advantages of the more resistant linings.

Non-Metallic Inclusions in Large 08KP Steel Ingots. A. I. Koshik and V. K. Barzii. (*Stal'*, 1957, (10), 943–947). Large silicate inclusions tend to segregate in the lower part of the ingot, and complex oxide inclusions in the upper and lower parts of 14-t and in the cellular blister region of 9-t ingots.

On the V-segregates of Large Steel Ingots. M. Kawai. (*Tetsu to Hagane*, 1957, **43**, May, 528–532). [In Japanese]. A continuation from *ibid.*, 1957, Apr., 431.—K. E. J.

Industrial Continuous Casting of Steel. (*Iron Coal Trades Rev.*, 1957, **195**, Dec. 6, 1328–1329). Progress at Low Moor is outlined.

Continuous Casting of Steel. M. S. Boichenko, V. S. Rutes, and N. A. Nikolaev. (*U.S.S.R. Acad. Sci. Press, Popular Science Series*, Moscow, 1956, 8vo, pp. 51). The first half of this book is devoted to non-Russian continuous steel casting plants and gives details of speed of casting, type of product, output, etc. The second half of the book deals with Soviet continuous casting plants and describes the machines at Krasnoye Sormovo (Gorki), Novo Tula (South of Moscow) and the Red October works (Stalingrad). Finally, there is a chapter on the economics of the process. The Russians began research on the continuous casting of steel in 1944. Both horizontal and vertical installations are described. The merits of various shapes of continuously cast product are discussed. Details of mould design, water cooling, use of stoppered ladles and tundishes are given. Within the compass of the last 24 pages, this publication gives most useful information about Russian progress in the continuous casting of steel up to 1956.—R. S.

Continuous Casting: Review and Outlook. R. Easton. (*J. Met.*, 1957, **9**, Aug., 1045–1048). The author first gives an outline of some of the different processes used in continuous casting of copper, brass, and aluminium, and then discusses briefly the present position of continuous casting of steel.—G. F.

Economics of Continuous Casting in a Converter Steel Plant. J. Savage and J. S. Morton. (*J. Met.*, 1957, **9**, Aug., 1052–1056). Based on the practical experience and achievements of the past ten years, the authors assess the range of application of continuous casting. Four examples of hypothetical continuous casting plants used in conjunction with converters and electric furnaces are considered, and their capital and operating costs are analysed and shown to give marked economies over conventional ingot practice. It is concluded that continuous casting may entirely replace conventional casting in works with outputs ranging from 80,000 to 300,000 t per year.

Continuous Casting of Three Types of Low Carbon Steel. F. G. Jaicks, L. E. Kraay, and M. Tenenbaum. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Aug., 1057–1072). This paper describes Inland Steel Co.'s assessment of the problems involved in integrating continuous casting of low carbon steels into an existing steelmaking plant, the study including the casting of rimming, semi-killed, and killed steels into 24 × 6½ in. sections. The plant used is described and the different operating conditions required for the three types of steel are discussed The results obtained in the casting studies are interpreted so as to indicate factors that must be considered in assessing operating limitations and plant capacities.—G. F.

Investigation of the Process of Continuous Casting of Steel. V. S. Rutes and D. P. Evteev. (*Continuous Casting of Steel. Report of the First All-Union Conference of Continuous Steel Casting*, 17 to 19th October, 1955. *U.S.S.R. Acad. Sci. Press, Moscow*, 1956, 5–48). [In Russian.] The depth of liquid piping in a continuously cast ingot, which determines the dimensions of the casting installations, and also variation in skin thickness of the solidifying billet depend on casting speed, cross-sectional area of the billet and the physical properties of the steel. An increase in casting speed increases the total heat extraction per unit of time and reduces the amount of heat extracted per kg of steel, both in the mould and in the zone of secondary cooling. In the top half of the mould where there is direct contact with the walls, the heat extraction currents are of the order of 800,000 to 1,500,000 kcals/m²/hr. The formation of a gas gap between slab and mould walls in the lower part of the mould reduces thermal currents to 200,000 to 400,000 kcals/m²/hr. Optimum conditions of secondary cooling are discussed. **An Examination of the Quality of Steel Ingots Produced By Continuous Casting.** N. A. Nikolaev. (49–61). This reviews factors which determine the quality of the continuously cast product and discusses the optimum shape of casting (comparing rounds, squares, ovals and slabs). **Design of a Continuous Casting Machine for Steel at Novo Tula.** V. P. Druzhinin. (62–66). The author gives details of the vertical continuous casting machine at Novo Tula (south of Moscow) for producing 24 × 8 in. slabs at speeds of up to 7 ft per minute. Conditions for obtaining good surface and structure are outlined. **Operation of a Continuous Steel Casting Machine at the Krasnoye Sormovo Plant (near Gorki).** A. V. Khripkov. (67–72). The vertical underground continuous casting machine at Krasnoye Sormovo is described. It is a twin-strand machine. The advantages of this method are enumerated. The results of four months' operations are given. **An Examination of the Quality of Continuously Cast Products.** N. L. Komandin. (73–83). The mechanical properties of continuously cast billets after

normal degrees of hot working are discussed. Small cracks are completely welded up during hot working, even with small reductions. Cracks appear to be the result of very high stresses in the billet during the last stage of solidification. This can be remedied by careful control of withdrawal and water consumption for secondary cooling. **Features of the Continuous Casting of Special and Carbon Steels.** M. S. Boichenko. (84–99). This chapter discusses the choice of continuous casting methods and various conditions of cooling. Physical properties of solid and liquid metal during the continuous casting process are tabulated. The peculiarities of steel in relation to continuous casting and the relationship between steel quality and type of continuous casting process are reviewed. Fundamentals of design of continuous casting installations are discussed. **Semi-Continuous Casting of Stainless Steel.** B. Z. Kononov. (100–110). The method of starting off with a dummy bar and conditions of pouring are described. The defects met with are noted and investigations to effect improvements are reported. The prevention of floating crusts was attacked by elimination of N_2, using a neutral atmosphere and wooden frames to keep out crusts were tried. Casting speed was increased and lubrication improved. The mechanism of the process was studied and future developments are discussed. **A Horizontal Continuous Steel Casting Machine.** M. F. Goldobin. (111–118). A description is given of a horizontally inclined continuous casting machine in which the ingot solidifies in a moving channel formed by moulds mounted on chain links attached to two steel conveyor belts. **The Planning of Goldobin Horizontal Continuous Steel Casting Machines in Medium Output Hearth Plants.** G. A. Garbuz. (119–122). The economic and technical features of the Goldobin continuous casting system at the Sulinsk plant are reviewed. The horizontal machine takes up more space in old steel plants than the vertical machine. Special attention will have to be paid, with horizontal machines, to the auxiliary equipment and to mould consumption. In spite of this, good results have been obtained with four of these machines at the Sulinsk plant. **Continuous Casting of Small Steel Ingots with Subsequent Cross Rolling without Intermediate Reheating.** A. S. Nikiforov. (123–128). This deals with the production of crusher balls 60 and 40 mm diameter by a method combining continuous casting with subsequent cross rolling of the product, quenching and tempering without intermediate heating. There is an interesting diagram of the entire process from molten steel to finished balls combined in a single installation. **Typical Designs of Industrial Continuous Steel Casting Plants.** V. V. Ful'makht. (129–133). An account is given of the method of withdrawal and feeding of the mould from the ladle and of reasons for choosing the underground type of vertical machine instead of the tower type. Multi-strand, vertical machines with movable moulds, casting through a stoppered tundish and installed in underground pits are recommended. Automatic control is being developed for all the operations. **Results of Research and Perspectives on the Introduction into Industry of the Continuous Casting of Bars Instead of Ingots.** L. I. Morozenskii. (134–144). Conditions of solidification, layout of plant, and steel properties are discussed. **Basic Factors Which Determine the Technology of Continuous Steel Casting With a Moving Mould.** I. Ya. Granat. (145–155). Deals with the mathematics of the movement of the solidification front for various shapes of products, the strength of the casting shell, the formation of the axial zone and the question of mould wall thickness. **Inclined Continuous Casting of Steel.** E. S. Permitin. (156–163). An inclined continuous casting machine designed in 1951 is described. Data on the productivity of the machine and the quality of the product are given. The product was improved by increasing the angle of inclination of the mould from 30° to 40° and replacing the pouring trumpet by a 1-ton stoppered tundish. **Features of the Moulding of Bar by Continuous Casting.** O. D. Zigel (164–177). Defects are figured. **Oxygen Cutting in The Continuous Casting of Steel.** O. Sh. Spektor. (178–187). This article discusses the relationship of cutting speed to the power of the oxygen jet and metal temperature. A method of determining the consumption of oxygen and acetylene per ton of metal is described. Optimum conditions for cutting stainless steel continuous castings are given. **Solidification and Properties of Liquid Steel Under Continuous Casting Conditions.** A. P. Pronov. (188–198). Methods of testing molten metal viscosity are described. The mechanism of the formation of hot cracks is discussed and details are given of the freezing of steel in the Goldobin horizontal continuous casting machine. **Gases and Non-Metallic Inclusions in a Continuously Cast Steel Ingot.** V. I. Yavoiskii. (199–211). This article gives reasons for the importance of careful steelmaking for the continuous casting machine. **Examination of Mechanical Properties of Steel During Solidification and an Analysis of the Process of Formation of Hot Cracks in Continuous Casting.** L. M. Postnov and B. B. Gulyaev. (212–222). The effect of carbon content on hot workability is discussed, especially in relation to hot cracking. The properties of the solidified shell of the continuous casting and the effect of stresses is discussed. **Effect of Inoculation Additions and Conditions of Solidification on the Quality of the Continuous Casting Shell.** V. E. Neimark. (223–240). Deformation of the shell is caused by a low rate of nucleation of the crystals and non-uniform crystal growth. Zinc, tin, lead and aluminium reduce deformation and increase the solidification speed. It is shown that deformation of the shell increases when heat extraction during solidification is stepped up. **Mechanism of Hot Tearing of Steel Castings.** V. N. Saveiko. (241–251). A review of previous theories is given and critically discussed with examples. **Pouring Temperature and Hot Tearing.** V. G. Gruzin. (252–260). An account of investigations on the laboratory scale and of full-scale observations tending to confirm the findings is given. Hot tearing was least in pouring close to liquidus temperature and the resistance of austenitic 10 Kh 15N15TL steel tending to solidify in a columnar dendritic form was much lower than that of fine-grained pearlitic steel. Mechanisms are advanced depending upon details of solidification processes. **A New Method for the Determination of Linear Contraction, Stress, and the Resistance of Alloys to Hot Tearing.** N. A. Trubitsyn. (261–266). Apparatus is described incorporating transducers which measures linear contraction, stress, resistance to hot tearing and temperature simultaneously. A cylindrical or stepped specimen is used cast into the flank of the apparatus. Preliminary results are given. **Planned Research into the Continuous Casting of Steel.** A. M. Samarin. (267–270). Many of the problems which will have to be solved before continuous casting becomes commercial are touched on. These include mould design, protection against oxidation, a complete study of the properties of liquid metal and automation of the process. The necessity for carefully coordinating research is stressed.—R. S.

Study on Ingot-Making Practice. VI. Deoxidising Reactions at Temperatures Near the Solidifying Point of Molten Steel. I. Deoxidation of Silicon and Non-Metallic Inclusions. S. Maekawa and Y. Nakagawa. (*Tetsu to Hagane*, 1955, **41**, Sept., 962–964). [In Japanese.] For four samples (compositions given), the relationships between heating temperature and SiO_2 produced, and heating time and SiO_2 produced, are shown. Various inclusions were examined microscopically after extraction.—K. E. J.

Study on Rimmed Steel. I. Change of Oxygen and Other Elements during the Solidification of Molten Steel. M. Yoshida. (*Tetsu to Hagane*, 1955, **41**, Sept., 1034–1036). [In Japanese.] Graphs of the accumulation of S and O in the liquid interior of the ingot up to 20 min after pouring are shown, as is the relationship between O and C in liquid metal during solidification.—K. E. J.

Experimental Study on Temperature in the Process of Refining Top-Pouring Rimmed Steel. K. Izu. (*Tetsu to Hagane*, 1955, **41**, Sept., 957–958). [In Japanese.] Relationships are sought between the degree of rimming action and the tap temperature, the tap temperature and the amount of ingot skull, and the bath temperature and the carbon content.—K. E. J.

Formations of Inclusions in Steelmaking. T. Tanoue. (*Tetsu to Hagane*, 1955, **41**, Sept., 1068–1069). [In Japanese.]—K. E. J.

On Surface Defects of Rimmed Steel. T. Horigome. (*Tetsu to Hagane*, 1955, **41**, Sept., 958–960). [In Japanese.] A statistical enquiry is made into the effects of heating time, charge weight and other parameters on the incidence of defects. The defects are examined for Sn, As, Cu and S contents and for grain size.—K. E. J.

Sub-Surface Blowholes of Semi-Killed Steel Ingots and Seams of Products. T. Kinoshita. (*Tetsu to Hagane*, 1955, **41**, Sept., 960–962). [In Japanese.] Blowhole indices are derived on the basis of size and depth of the blowholes, and one such index is correlated with the number of seams at various positions in the billet.—K. E. J.

On the Prevention of Ingot Scabs in Cylinder Plates and Spiral Sheets. Y. Ozawa. (*Tetsu to Hagane*, 1955, **41**, Sept., 964–965). [In Japanese.]—K. E. J.

FOUNDRY PRACTICE

Forty Years In and Around Foundries. W. L. Hardy. (*Found. Trade J.*, 1958, **104**, Jan. 2, 3–10). A survey of progress in coremaking, moulding shops, materials and inspection techniques, melting, pouring and dressing, centrifugal and CO_2 methods, shell moulding and the use of nodular iron is presented.

Ductile Iron Moves In. (*Steel*, 1957, **141**, Dec. 16, 110, 112, 114). Uses in steelworks are reviewed including coke oven doors, sintering pallets, quenching cars, pig-irons, mould conveyors, O.H. charging boxes and various soaking pit and rolling mill parts.

Recent Developments in the Manufacture of Castings. J. L. Rice, R. W. Ruddle and P. A. Russell. (*Foundry Trade J.*, 1957, **103**, Dec. 5, 665–672; Dec. 12, 693–702; Dec. 19, 729–735). A review of developments in recent years. Established processes, alloy development, inspection and future trends are surveyed. Iron, but not steel, is included with non-ferrous alloys. The shell moulding process, the CO_2 process, investment casting and the Shaw process are considered and grey, malleable and spheroidal graphite irons are dealt with as well as Cu and Al alloys, Mg alloys and high-temperature compositions. Future trends are then suggested.

Improved Foundry Compositions. A. Wittmoser. (*Met. Prog.*, 1957, **71**, Jan., 84–87). The diverse effects of various trace elements on several alloys in the Fe–C group are summarised, and the author shows how the systematic evaluation of data on trace elements has already solved problems of practical significance.—G. F.

Moving Foundry Materials. No. 4. Monorail Conveyors. R. G. Wieland. (*Mod. Castings*, 1957, **32**, Dec., 30–33).

Leicester Founders Build Their Own Plant. (*Foundry Trade J.*, 1957, **103**, Nov. 28, 633–638). Richards Foundries Ltd. built a new sand plant which is described and illustrated with diagrams. Other improvements are also reviewed, including a motorized driving drum and a composite moulding box.

New Foundry Departments for Thomas Crompton & Sons. (*Foundry Trade J.*, 1957, **103**, Nov. 7, 555–557). Plans of the old and new foundries are given with a brief account of the plating and other new departments.

Progress at Ford's New Foundry. (*Process Control Autom.*, 1958, **5**, Jan., 14–18). The new foundry at Dagenham is described and illustrated. Mechanization is especially considered and a summary of dimensions and equipment is added.

Pipe Maker Installs Water-Cooled Cupola. J. E. Rehder. (*Can. Metalw.*, 1957, **20**, Nov., 30–31, 34, 36, 69). The installation of Canada Iron Foundries Ltd., Toronto is described, with an account of operation and advantages of the hot blast.

Study of the Permanent-Wall Type Furnace by Forced Cooling. R. Sato. (*Tetsu to Hagane*, 1955, **41**, Sept., 995–997). [In Japanese.] Operating data for the furnace are given; the distribution of temperature in the lining is shown and erosion data for the lining are given—K. E. J.

Better Utilization of the Cupola. L. Oltrasi. (*Fonderia*, 1957, **6**, June, 247–259). [In Italian]. The author discusses recent technical and practical developments in cupola operation. A brief historical introduction is given, combustion processes and chemical reactions are studied. Cold and hot blast operation are compared and finally the basic cupola process and the duplex operation of cupola and electric furnace are examined. Much technical and operational data and charts are given.

The Injection of Swarf into the Cupola. S. H. Chrobok. (*Engineer Foundryman*, 1957, **22**, Oct., 48–55). After a discussion of the problem and previous attempts to solve it, a new injector is illustrated and described and its performance given. Other points are made in discussion.

Cupola Exhaust Gas Analysis Method. T. Shimomura and M. Yamamoto. (*Tetsu to Hagane*, 1957, **43**, June, 632–637). [In Japanese.] Comparative trials were made of chemical, conductivity and specific gravity methods for analysing exhaust gases, particularly CO_2, with a view to assisting routine operation. For routine work it was found that CO_2 was best measured with a semi-automatic absorption meter, which is both simple and speedy in operation.—K. E. J.

Scientific and Applied Aspects of the Production of High Strength Cast Iron with Spheroidal Graphite Structure (Nodular Cast Iron). L. I. Fantalov. (*Production of High Strength Cast Iron, edited by L. I. Fantalov, U.S.S.R. Academy of Sciences Press, Moscow*, 1955, 3–12). [In Russian]. F., after emphasising the importance of developing high-strength, light-weight cast irons, deals with production technology, heat treatment, classification, and the applications of nodular cast irons. **Formation of Graphite in Magnesium-Inoculated Cast Iron.** K. P. Bunin and Yu. N. Taran. (13–35). The solidification process and the nature of spheroidal graphite are described. When the eutectic solution surrounding the graphite inclusions is undercooled, a compact, austenitic envelope isolates these inclusions. The part played by magnesium at this stage of crystallization combines with the increase in undercooling and the growth in the number of nuclei and the decrease in the rate of growth of the graphite inclusions. **Structure of Graphite in Iron-Carbon Alloys.** D. P. Ivanov. (36–62). The phenomena which occur in Mg cast iron can be better understood by a more detailed study of the process of primary crystallization of graphite when iron-carbon alloys are cooled. I. deals with the formation of temper carbon in wrought cast iron, examines the processes of solidification of Mg cast iron and of normal grey cast iron and the conditions of formation of mixed and transitional forms of graphite bodies. The structure of spheroidal graphite is discussed. **Phase and Structural Transformations in the Heat Treatment of High Strength Nodular Cast Iron.** M. N. Kunyavskii and T. G. Demidova. (63–92). After classifying the phase and structural transformations and types of heat treatment, the authors deal with the graphitization of eutectoid cementite (second stage of graphitization), the effect of the rate of cooling in the critical temperature range on the structure and properties of cast iron, the solution of carbon in the gamma phase, hardenability, the isothermal breakdown of austenite and isothermal quenching and tempering. **Nodular Cast Iron as a New Structural Material in Engineering.** I. O. Tsypin. (93–100). The author compares the mechanical properties of various kinds of cast iron, steel, bronzes, brasses and Duralumin. He discusses the effect of wall thickness of castings on the structure and properties. Details of Soviet types of ductile nodular cast iron are presented. No concrete examples of the use of nodular iron are stated but it is recommended for diesel engineering, rolls, carriage frames, roller table rolls, tractor crankshafts, parts of oil-drilling equipment, bed plates for light presses and shears, etc. **Some Peculiarities of Structure Formation and of the Nitriding of Magnesium Nodular Cast Iron.** A. F. Landa and V. D. Yakhnina. (101–113). The Si and C in high strength cast iron can form chemical compounds with Mg which cause the solution of the latter element in the liquid iron. Mg is dissolved in the crystallized austenite and graphite and any excess, due to supersaturation, is transferred to the surface of the crystals as a constituent of the intercrystalline phases. The concentration of Mg is irregular. Short time homogenization adjusts the concentration of Mg in the ferrite. Among the causes of spheroidization of the graphite is the change in surface stresses on the graphite (mother) liquor interface caused by the solution of Mg in the matrix and its interaction with graphite. The amount of dissolved Mg and the nature of the distribution of the nuclei affect the form of graphite. The introduction of small amounts of Mg to cast iron facilitates the production of a nitrided layer. The nitriding of magnesium-inoculated cast iron enables a case 0·3 mm deep to be obtained in 3 to 5 hours. **Properties of Nodular Cast Iron at High Temperatures and the Possibilities of Its Application for Fittings.** I. G. Girshovich, S. K. Maksimov and V. A. Mikhailov. (114–123). The properties of nodular cast iron at elevated temperatures, both with short time and long time loading have shown that the properties of this material approach those of carbon steel and are quite suitable for fittings operating at temperatures of up to 425° C and at pressures of up to 0·25 t/in², provided suitable measures are taken to prevent brittleness. **Wear Resistance of High Strength Cast Iron Subjected to Sliding Friction.** M. S. Shkalikov. (124–136). Maximum wear resistance is exhibited by cast iron having a pearlitic structure. The content of free ferrite must not exceed 20 to 25%. Pearlitic cast iron containing nodular graphite, under conditions of non-lubricated friction, is not inferior as regards wear resistance to wrought iron containing granular pearlite and is many times more wear resistant than grey iron and many of the light anti-friction alloys. Under conditions of friction with lubrication, nodular cast iron exhibits better wear resisting properties than do some brasses up to the critical region of friction. Conditions under which nodular cast iron can be used to replace some light alloy bearing metals are stated. **Hot Working of High Strength Nodular Cast Iron.** E. P. Unksov and D. I. Berezhkovskii. (137–150). Pearlitic and ferritic cast iron having a spheroidal graphite structure can withstand a marked degree of plastic deformation in the range 840 to 1040° C. Pearlitic cast iron containing nodular graphite is more ductile in the hot state than a ferrite-based iron. Cast iron containing 0·1% P can be rolled, forged and stamped. Examples are given. **Magnesium-Inoculated Cast Iron and the Production of High Strength Iron Castings in Heavy Engineering.** B. S. Mil'man. (150–157). Difficulties associated with the introduction of large amounts of Mg to large ladles and with the specialized (non-mass production) nature of engineering castings are discussed. Examples are given, however, of the way this material has been introduced in the diesel engineering industry and of how it has led to economies. **Production of High Strength Cast Iron.** A. I. Klauzen. (158–162). The production of nodular graphite castings having a pearlitic structure can be applied to castings with wall thicknesses of greater than 10 mm without annealing. The addition of Mg by means of Mg–Si alloys is not the complete answer to the production of castings with wall thicknesses of less than 10 mm. Methods must be developed of introducing the Mg in the form of briquettes made of a mixture of Mg chips and graphite or other fillers. Problems of transporting and storing Mg chips are discussed. **Cast Diesel Crankshafts Made of High Strength Cast Iron to Replace Forged Steel Crankshafts.** P. V. Berezin and I. B. Meerovich. (163–172). This article reviews the work of the Russky Diezel (Russian Diesel) plant and the Soviet Research and Development of the Ministry of Heavy Engineering on the production of cast crankshafts made of nodular cast iron for mass produced six-cylinder engines of 600 H.P. and operating at 300 r.p.m. Semi-product weight was 6·3 t for steel and 2·1 t for cast iron, finished weight 1·9 and 1·7 respectively. The cost of the cast iron crankshafts was about a quarter of that of the steel parts and the cycle of production was three times as long for steel. **Trial Casting of Rolling Mill Rolls Made of Cast Iron Treated with Magnesium.** A. S. Beshlyk. (173–181). The method of casting the rolls is described and illustrated diagrammatically. A set-up for introducing Mg into the ladle is shown. Application to the production of sheet rolls and section mill rolls is discussed. **Development Trials for the Production of Magnesium-Inoculated Cast Iron.** G. I. Kletskin and L. Ya. Ozerina. (182–191). The trials were carried out under production conditions for parts of lathes and forging presses weighing 100 to 3400 lbs. Capacity of the ladles used was 2 to 3·5 t. Relationship between initial S content and the requisite amount of Mg for inoculation is stated. The Stankolit plant has been producing nodular parts since 1953. **Mastering of the Technique and Introduction of High Strength Cast Iron.** I. P. Petrov. (192–199). Experience at the Syzransk hydroturbine plant leads to the following conclusions: (1) The necessary superheating of cast iron for Mg treatment can be effected in cupolas fitted with regenerators or by blowing the iron with oxygen directly in the tapping spout; (2) The rational method of adding Mg is in the fore-hearth of the cupola or in a covered ladle; (3) Optimum mechanical properties are obtained by casting in chilled moulds.—R. S.

Pressure Diecasting of Steel. P. N. Bidulya, I. I. Bobrov and K. N. Smirnova. (*Lit. Proizv.*, 1956, (7), 1–4; *Eng. Dig.*, 1957, **18**, Jan., 23–24). Requirements of die design are set out and a new type of mould is described. The process and the microstructures produced and the mechanical properties of the products are discussed.

Austenitic Manganese-Steel Technology in an Australian Foundry. H. Thomas. (*Found. Trade J.*, 1958, **104**, Jan. 2, 11–14). Melting, pouring, moulds and cores, heat-treatment, analysis, testing and metallography are outlined with an appendix on the determination of Mn.

Steel Wheels in Green Sand. L. DeBoer. (*Mod. Castings*, 1956, **30**, Oct., 34–37). An illustrated account of the casting of railway wheels by American Brake Shoe Co. is presented. Layout, mould section risers and gating are described and melting, pouring and finishing considered.

Chance Vought Uses More Steel Castings. S. K. Hodgson. (*Mod. Castings*, 1958, **33**, Jan., 26–28). Castings for supersonic aircraft are described.

Sands for Moulding. (*Mech. World*, 1957, **137**, Sept., 417–418). Properties of sands, and defects that may be produced by unsuitable qualities are reviewed.

Moulding Characteristics of Allahabad Sand. U. C. Sharma, R. M. Krishnan and B. R. Nijhawan. (*J. Sci. Ind. Res.*, 1957, **16A**, Nov., 517–522). Tests on a sand are reported. It required washing in a hydroclassifier to be suitable for moulding, and then required the addition of bonding materials.

Hardness Testing of Foundry Sand. W. Ruff. (*Giesserei*, 1957, **44**, Dec. 19, 766–769). The author describes a modification of the GF-hardness tester for foundry sand. This consists of increasing the tension of the main-spring from 188 to 688 g. and by reduction of the spring constant from 51 to 40 g/mm and of increasing the number of turns from 16 to 31. Results obtained with the two modifications of the hardness tester are given in tables and graphs.—T. G.

Spheroidal Graphite Irons. A. Coinde. (*Bull. Cercle Etudes Mét.*, 1957, **7**, June, 151–178). A comprehensive discussion of spheroidal graphite cast irons is presented. The production of the irons by innoculation with Ce, Ca, and Mg is first mentioned and then a more

detailed account of the use of Mg is given. Modern views on the theory of spheroidal graphite formation are discussed. Various forms of thermal treatment and their influence on the properties of spheroidal graphite irons are explained. The mechanical and magnetic properties are given in tabular form.—B. G. B.

The Use of Hard Cast Iron in Machine Tool Construction. L. B. Blinnik and V. N. Semenov. (*Stanki i Instrument*, 1956, (12), 25–27). [In Russian]. This experimental study determined the optimum microstructure corresponding to the optimum service of this material in industry. The data obtained give ample details of pearlite-ferrite castings, of pearlite normalization, of ferrite annealing and surface tempering. The results of tensile and compression stresses, hardness, elasticity etc. are also given.—L. H.

Researches on the Effects of Sodium and Titanium Slags on the Chemical, Structural, Mechanical and Casting Properties of Grey Cast Iron. B. Sochor and I. Pavlik. (*Slévárenství*, 1957, **5**, (7), 25–34). [In Czech]. Experimental casts were made in a 6·5-in. dia. cupola which had an output of 220 lb/h, individual tappings giving 20–30 lb. Cold blast was used in general; blast pre-heated to 900° F was used only occasionally. Cast iron containing 3·5% C, 2% Si, 0·45% Mn, 0·50% P, and 0·08% S was melted under acid and basic slags covering a range of basicity. These were partially dressed with titanium and sodium additions. It was found that (*a*) the refining ability of currently used acid slags is negligible, but by changes in composition the fluidity may be increased and a small improvement in the quality of the cast iron can be attained; (*b*) acid slags containing Ti dressings did not improve the mechanical properties of the cast iron noticeably, but Na dressings improved them by about 25%. (*c*) The refining action of basic slags was confirmed. The mechanical properties are not noticeably affected, but the fluidity of the iron is increased to double the value attained with currently used slags, on adding Na dressings. (*d*) Preparation of basic slags with fluxes can improve almost all mechanical properties of the iron by about 25%. Na additions resulted in higher desulphurization without affecting the mechanical properties. (*e*) Increasing slag fluidity and blast temperature were beneficial in aiding the melting process and improving the quality of the iron.—P. F.

A Footnote to the Study of the Isothermal Transformations of Cast Irons. R. Verriest. (*Fonderie Belge*, 1957, May, 109–110). The application of data on the isothermal transformations of cast irons to the problem of producing wear-resistant cylinder liners is referred to and recent work on wear-resistant cast irons is summarized.—B. C. W.

Casting Carbon Steels Containing Boron: Further Soviet Experience. W. G. Cass. (*Iron Steel*, 1957, **30**, Sept., 456). A brief account is given of recent Russian research on methods of introducing B into steels and on its effect on the properties of castings, with special reference to the reduction of wear in tractor driving wheels.—G. F.

Systematic Control Guides Production of High Quality Grey Iron Castings. A. W. Schneble. (*Ind. Heat.*, 1957, **24**, Sept., 1860, 1862, 1864, 1866, 1871–1872, 1874). Layout and operation of the Advance Foundry Co., Dayton, Ohio, is described.

Some Advances in Development of High-Duty Malleable Cast Iron. B. Thyberg. (*Gjuteriet*, 1957, **47**, Nov., 179–188). At the Husquarna Works research has found the way to production of pearlitic malleable iron with tensile strength of 62–67 kg/mm², yield point 38–42 kg/mm², and elongation 5–8%. "Inverse greyness" and hardening are discussed. The effects of C, Si, Cu, Ni, and Mo are dealt with separately, and notes on manganese alloys and details of finished goods complete the article.

Equipment for Introducing Manganese into Cast Iron. S. I. Ryabukhov. (*Liteinoe Proizvodstvo*, 1957, (5), 14–15). A description is given of an apparatus constructed at the Gorky Motor works, in the form of a rotary drum capable of receiving 100 kg of molten cast iron from the furnace at a temperature of 1460° and provided with a regulating mechanism for introducing the Mn. The reaction is completed in a very short time and the final temperature is 1400°.—L. H.

The Use of Toughened Iron in the Iron Industry. E. O. Lissell. (*Varm. Bergemann. Ann.*, 1957, 53–89. Five types of toughened iron for casting and a general chemical analysis are followed by a description of qualities (also tabulated). Examples are given of usage for large castings. Rolling mills are described in some detail.

The Feasibility of Producing Nodular Cast Iron by Adding Metal Compounds. N. Cuhadar. (*Bull. Tech. University Istanbul*, 1957, **10**, 28–38). [In German]. Experiments have been carried out to determine the feasibility of replacing Mg, Ce, and Ca as additions in the production of nodular iron by Mg and Ca compounds. Two processes were developed from theoretical considerations and produced positive results. Further experiments are to be undertaken with the object of improving nodule formation by improving the method of adding the compounds and perhaps by inoculation of the melt with ferrosilicon.

Inverse Greyness in Malleable Cast Iron. C. T. Moore. (*B.C.I.R.A., J. Res. Dev.*, 1957, **7**, Oct., 68–79). After a preliminary investigation of inverse greyness in certain types of commercially produced blackheart malleable castings, the author studied the factors affecting the incidence of this defect in thin sections attached to a relatively heavier section of a test casting. Inverse greyness was found to increase simultaneously with mottle in the heavy section when the Al, Si, C or Mn content was increased. High casting temperatures and an increase in the thickness of the thin section also aggravated the defect. There was, however, no clear relationship between the amount of mottle and inverse greyness when varying the pouring temperature. The author suggests that inverse greyness occurs when design factors are such as to cause thin sections to cool rapidly at first, but relatively slowly during eutectic solidification.—L. E. W.

Alloy Cast Irons Can Solve Tough Problems. J. H. Culling and J. F. Wallace. (*Mat. Design Eng.*, 1957, **46**, Oct., 140–144). Chapters from a forthcoming book. Corrosion-resistant, heat-resistant, low-expansion, electrical resistance, and high-alloy ductile irons are reviewed. (16 references).

Rational Organisation of Magnesium Iron Castings Production. S. F. Gorbunov and M. M. Levitan. (*Lit. Proizv.*, 1957, **3**, (11), 8–10). [In Russian]. A method is described which was evolved to eliminate in foundries the difficulties associated with the introduction of Mg into the melts, and with heat treatment of the castings, in view of the greatly increased demand for this alloy instead of the ferritic-malleable variety. Additions of Mg are made directly in the ladle and the resulting magnesium iron, with even up to 4% C, does not show inclusions of cementite, and its pearlite structure does not exceed 15–25%.—L. H.

Treatment with Magnesium of Cast Iron Smelted in a Basic Cupola. G. I. Kletskin. (*Lit. Proizv.*, 1957, (9), 21–26). [In Russian]. In this article the investigation and application of methods of producing Mg cast iron for making 150–1500-kg castings are described. A special evaporator-container was developed for the Mg addition operation, and details of this are given. Experiments with irons containing 0·03–0·20% S showed that S concentration had an important effect on product quality and for producing a low-sulphur iron the use of basic slags in the cupola was adopted. The basic-lined cupola used is described, the influence of various factors on its operation are considered and optimal conditions are outlined which secure a product relatively free from defects, including "dark spots."—S. K.

Austenitic Cast Iron with Nodular Graphite. F. N. Tavadze, I. A. Bairamishvili, and D. V. Khantadze. (*Lit. Proizv.*, 1957, **3**, (7), 16–17). [In Russian]. The results of the investigation show that cast iron with nodular graphite in an austenite base must be obtained during the casting because the subsequent thermal treatment does not give satisfactory results. The graphitic forms are distorted and pearlitic transformation takes place.—L. H.

Influence of Temperature of Superheating and Temperature of Introduction of Magnesium on the Properties of Cast Iron with Spheroidal Graphite. E. E. Farafonov and M. S. Kolmakova. (*Lit. Proizv.*, 1957, (3), 14–16). [In Russian]. Various experiments are described in which temperature of pouring and of introduction of Mg were altered and the effects of the changes on the properties of the cast iron were determined. Besides mechanical properties, determinations were made of fluidity, microstructure and chemical composition, the latter enabling the Mg uptake to be found. The conclusions drawn were confirmed in plant tests. It was found that the quantity of Mg absorbed depends on melting conditions as well as on metal temperature in the ladle.

Properties of the Surface Structures of Decarburised Castings from Ductile Cast Iron. M. A. Krishtal, I. P. Fominykh, and A. Ya. Tsentlin. (*Lit. Proizv.*, 1957, (8), 22–23). [In Russian]. Experiments elicited the mechanism of formation of these surface defects. They appear in the first stage of graphitization when accompanied by decarburizing, or if decarburizing follows graphitization, the flaws are bigger.—L. H.

Structural Constitution and Transformation Characteristics of Very Rapidly Solidified Cast Iron Treated with Magnesium. R. Mitsche. (*Berg. Hütten. Monatsh.*, 1957, **102**, July/Aug., 204–213). By studying the properties of very rapidly chilled cast iron samples, it was possible to draw conclusions as to inhomogeneities existing in the liquid condition. The investigations were carried out on melts which were either untreated, treated with an Mg–Ca–Si alloy, or subsequently inoculated with FeSi. In spite of the high rate of cooling, equal to several thousand degrees per second, the thin test pieces varied considerably in structure, but it could not be stated with certainty to what extent these differences corresponded to inhomogeneities in the original melt. Annealing trials on the chilled samples provided direct evidence of the mechanism of formation of spheroidal graphite. (13 ref.).—L. D. H.

Ringpot Casting of Piston Rings for Diesel Engine Locomotives. I. I. Frolov. (*Lit. Proizv.*, 1957, **3**, (7), 4–5). [In Russian]. The article gives a detailed technical description of the process.—L. H.

Tests on Piston Rings of Inoculated and Spheroidal Graphite Cast Irons. M. Curzytek. (*Prz. Odlew.*, 1957, **7**, (9), 256–263). The properties required are discussed and a comparison of gravity-poured and centrifugally cast rings of inoculated iron and of centrifugally cast spheroidal graphite iron is made. From published results and from one year's practical experience the advantages of spheroidal graphite iron are considered.

The Induction Mixer in the Modern Iron Foundry. A. Tagliaferri. (*Fonderia*, 1957, **6**, Aug., 337–340). [In Italian]. The technical and economic advantages of the induction hot metal mixer are discussed. Its use especially in the preparation of special cast irons is described.—M. D. J. B.

Steel Castings in Air Frames. S. K. Hodgson. (*Prec. Met. Mold.*, 1957, **15**, Oct., 37–38). Wing hinge castings in 410 stainless steel are described.

Moulding for Steel Castings. L. B. Hanneysee and N. K. Rickard. (*Inst. Brit. Found. Austr.*, 1957, **8**, 79–88). The production of several castings is described to illustrate the problems of high liquid and solid contraction in the moulding of steel.

Production of Steel Castings for Hydraulic Turbines. N. D. Vasil'ev. (*Liteinoe Proizvodstvo*, 1957, (5), 5–10). On the basis of these experimental results it has been found best to cast the rotor column sections without bottoms and to core the solid sections to a depth of 250–300 mm. This reduces the weight of the stator by 6–8%, shortens the work of welding, and reduces the consumption of electrodes. This casting of turbine sections in the Irkutsk Works economized 15 t of liquid metal for each unit and shortened the welding time by 40%.—L. H.

The Production of Ferrochromite Castings. J. Štengl, J. Čechura, and J. Hykel. (*Slévárenství*, 1957, **5**, (6), 171–175). [In Czech]. The casting technology is discussed with reference to a number of specific examples.

Castings of Acid- and Heat-Resisting Chromium Alloys. K. I. Vashchenko and L. I. Rostovtsev. (*Lit. Proizv.*, 1957, (4), 7–10). [In Russian]. The composition of chromium alloys for acid- and heat-resisting castings is discussed and tests of two new marks of such alloys are described: 25Kh18L (0·2–0·3% C, 17–20% Cr) and 30Kh20L (0·25–0·35% C, 20–23% Cr) both with 0·8% Mn, 0·8% Si, $<$ 0·045% P, and $<$ 0·04% S. The Cr content was chosen to give 14–17% Cr in the chromium ferrite with a probable combination of 3–6% of the element as carbide; the C content was chosen to give good casting properties. Results of corrosion and mechanical tests on these and other types of alloy are given and discussed and microstructures illustrated. On the whole the new alloys proved superior, except in castings of varying thickness.—S. K.

Age "Custom" Properties Into 17-4PH Castings. D. D. Burgan. (*Iron Age*, 1957, **180**, Aug. 29, 67–69). Properties obtainable from 17–4 precipitation-hardening stainless steel castings are explained. By varying annealing temperatures between 850° and 1200° F strength and ductility can be adjusted.

Parts Made of Selected High Strength Cast Steels. R. J. Ely. (*Prec. Met. Mold.*, 1957, **15**, Nov., 39–40, 96–97, 108–109). Investment casting of high strength steels with the strength–weight ratio about that of light alloys is considered, that is $>$ 180,000 psi. Test bar design is discussed and structures are shown.

Sandcrust Formation in Steel Castings. B. B. Gulyaev and Yu. F. Borovskii. (*Lit. Proizv.*, 1957, **3**, (6), 5–7). [In Russian]. The interaction between metal and sand mould is explained together with the physical and chemical processes taking place in the zone of contact.—L. H.

The Influence of a Carburising Blast on the Macrostructure of Steel Castings. P. G. Vinnichenko. (*Lit. Proizv.*, 1956, (9), 21–22). [In Russian]. It follows from the experimental data reported by the author that the conditions of heating have a considerable influence on the tendency of metals to dendritic crystallization.—L. H.

Characteristics of Sands for Self-Drying Cores. G. Joly. (*Fonderie Belge*, 1957, Sept., 223–230). Results are given of the drying time and the compressive strength obtained with 4 different core sands bonded with different amounts of self-drying oils. It is concluded that the amount of oil required increases with the fineness of the sand and in addition to the fineness index the grain size distribution and grain shape must also be considered.—B. C. W.

Foundry Sands, Earths and Mixtures. D. F. O'Connor and C. Morgani. (*Fonderia*, 1957, **6**, Sept., 395–407). [In Italian]. The authors describe in considerable detail the requirements of good foundry sands and moulding mixtures. Their mechanical and chemical properties are discussed and methods of preparation to secure best results are reviewed.—M. D. J. B.

Moulding Characteristics of Jubbulpure Pale Grey Sand. U. C. Sharma and B. R. Nijhawan. (*J. Sci. Ind. Res.*, 1957, **16A**, Sept., 424–427). The material was suitable for dry sand moulding of medium and large steel castings. Grading curves and analyses are given.

The Working of Moulding Materials. R. Cattaneo. (*Fonderia*, 1957, **6**, Sept., 392–394). [In Italian]. A brief review is given of the main precautions to be taken in the preparation of foundry sands to ensure good and consistent quality.—M. D. J. B.

A Comparative Study of the Effect of Starches and Moisture in Facing Sand. D. K. Southwick. (*Bradley's Magazine*, 1957, Autumn, 6–7). Starches had no appreciable effect on porosity but the effect of moisture is marked.

Practical Results with a New Mixing System for the Beneficiation of Moulding Materials. T. Klingenstein. (*Giesserei*, 1957, **44**, Aug. 1, 453–457). The rotary mixing machine (muller) and its mode of operation is described and illustrated. The testing of the mixing efficiency is discussed: the influence of mixing time on various properties such as compression and shear strengths is shown for both a rotary mixer and a pug mill. Mixing (or mulling) quality is defined in mathematical terms and related to the mixing time. Better mixing enables a saving to be effected in the amount of binder used.—R. J. W.

A New Machine for the Preparation of Foundry Sand. W. Geil. (*Fonderie Belge*, 1957, Apr., 73–76). A new sand mixer is described. It comprises a horizontal cylinder containing a high speed centrifuge and a roller, all of which rotate about their longitudinal axes in the same direction.—B. C. W.

Sand Slinger Moulding Machines. M. Grimault. (*Fonderie Belge*, 1957, June, 147–152). The development of moulding machines in which the sand is mechanically thrown into the mould is outlined and a description is given of the various types of fixed and movable sand slinger machines now available.—B. C. W.

Experiments on Sand Mixers and Sand Slingers. W. Gesell. (*Giesserei*, 1957, **44**, July 4, 397–404). The term "mixing" in this sense is first defined and the various types of mixer classified. For example, stirring machines and kneading machines are treated separately from the so-called mixing machines. The various tests of mixing on these machines are assessed, the results from these experiments are presented graphically. Similar tests are described for sand slingers, and combined mixers and slingers. In particular, the cooling effect in sand slingers has been studied. The phenomenon of the splitting of the sand grains is discussed.—R. J. W.

Rational Grinding with the Aid of Heavy Coarse Grinding Machines in Foundries. B. Dahlem. (*Giesserei*, 1957, **44**, July 4, 411–413). A concise article in which the influence of circumferential velocity, grinding efficiency and the diameter of the grinding wheel on the grinding process has been investigated. Economic efficiency and the cost of abrasives are then discussed. Finally the safety of the grinding operation is considered.—R. J. W.

Foundry Loams and Clays. J. Dlezek. (*Slévárenství*, 1957, **5**, (10), 289–297). The basic properties of loam and clay pastes and mixtures with sand were measured and some relationships were found useful for evaluating foundry loams and clays. A table is given applicable to loams for estimating suitability for moulding.

Labour Saving in Salvaging Moulding Sand. G. Trinks. (*Giessereitechn.*, 1957, **3**, Sept., 200–201). The many small moulds used for casting at the Wittenberge Sewing Machine Works were opened after casting, the castings were removed, and the moulding sand scattered was then shovelled into a heap in readiness for the following day's casting programme. The Central Foundry Projects Office at Leipzig was asked to suggest labour-saving devices. As no sand cutter machines of American make are offered for sale in Eastern Germany, the office suggested the use of machine units produced by the Leipzig Iron and Steel Works. These machines are illustrated and described.

Regeneration of Foundry Earths and Sands. E. Dall'Oglio and F. Carcano. (*Fonderia*, 1957, **6**, July, 307–310). [In Italian]. The authors show the possible economies which can be obtained by the appropriate treatment of foundry earths and sands. Methods of regenerating old sands are discussed.—M. D. J. B.

The Treatment of Foundry Sands For Shell Moulding. R. Cattaneo. (*Fonderia*, 1957, **6**, July, 311–316). [In Italian]. This article describes in some detail methods of agglomerating sands. Various agglomerants and resins are considered and the importance of selecting a good basis sand is stressed.—M. D. J. B.

Meet the Electronic Sandman. J. R. Young. (*Mod. Castings*, 1957, **32**, Nov., 36–37). Automatic control of moisture in sand by Cardillac is described.

High Temperature Moulding Sand Testing Machine "Thermolab." K. Futaki. (*Rep. Gov. Ind. Res. Inst.*, 1957, **6**, Jan., 60–68). A machine made by the Dietert Co. of Detroit is described.

Variations in Moisture—Enemy No. 1 of Wood Patterns. L. Lange. (*Gjuteriet*, 1957, **47**, Nov., 189–192). Increased humidity in the air causes wooden patterns to swell, which leads to variations in their dimensions. The author gives examples of foundry defects due to this and data from an investigation on the subject. The resulting figures vary with different seasons, conditions, and places, including those for the pattern store.

Investigations on Standards for Enamels for Foundry Patterns. S. Jarzebski and J. Gawronski. (*Prz. Odlew.*, 1957, **7**, (9), 249–256). Six compositions were tried. Hardness, impact strength, adhesion to patterns, absorptive capacities, resistance to flatting and blistering in contact with water and adhesiveness to foundry sands with temperature and bonding material were examined. It is recommended that drying time, hardness, impact strength, loss of gloss and scaling during cutting and adhesiveness to sands should be determined.

Properties of Moulding Materials at High Temperature. I. Expansion and Contraction by Slow Heating. K. Futaki. (*Rep. Gov. Ind. Res. Inst.*, 1957, **6**, Apr., 195–201). Silica and other materials were examined with regard to the $\alpha \rightarrow \beta$ transformation and the production of casting defects up to 2500° F. It was found that control of moisture, conditions of ramming, and sand distribution could not decrease the expansion more than 10%; that inorganic binders increase and organic binders decrease expansion and that synthetic sand increases in volume more than return sand.

Deformation of Sand Moulds in Steel Casting. A. M. Dubrovskii. (*Lit. Proizv.*, 1956, (9), 22–26). [In Russian]. This problem is considered in all its aspects; starting from the construction and use of the moulds and investigating the elastic deformations during temperature changes, etc. Conclusions were reached regarding the limiting pressures and the influence of temperature on these deformations.—L. H.

The Rates of Filling of Moulds and Methods of Measuring Them. F. Havlíček. (*Sbornik Vědeckých Prací Vysoké Školy Báňské v Ostravě*, 1957, **3**, (1), 69–79). [In Czech]. A most important prerequisite for sound castings is absence of turbulence during pouring. Methods of preventing turbulence based primarily on the control of pouring rates are discussed, and electrical measurement of the rates either with or without the use of an oscillograph are considered.—P. F.

Design and Casting Quality. H. Klotz. (*Giessereitechn.*, 1957, **3**, Oct., 221–225). The practical examples given to illustrate the optimum design of castings include a trough of 5 in. length, a chuck, a pulley, the housing of an electric motor, and steam cylinders.

The Production of Large Thick-walled Castings by the Riser-Pouring Method. F. Löwe. (*Giessereitechn.*, 1957, **3**, Oct., 219–221). The object of pouring through the riser is to supply an amount of heat to that part of the mould such that the iron in it remains liquid longest, enabling the casting to continue to absorb liquid metal during solidification.

Throttled Gating Systems. B. V. Rabinovich. (*Lit. Proizv.*, 1957, (3), 4–9). [In Russian]. The use of gating systems with constrictions is discussed. The main elements of gating systems are classified, and the design of throttled systems is considered, examples being given. Finally some rules for correction of faults are set forth.—S. K.

Exothermic Risers in Theory and Practice. V. Lupač. (*Slévárenství*, 1957, **5**, (6), 168–171). [In Czech]. Considerable economies were obtained, particularly through increased metal yield, by means of the use of exothermic riser sleeves based on thermit. The Al in the mixture was in the form of crushed chips, the oxygen bearer was ore of suitable granulometry. Specific applications are discussed.

Some Further Experiences with Exothermic Risers. J. Rous. (*Slévárenství*, 1957, **5**, (9), 261–264). [In Czech]. Three thermite based mixtures containing various amounts of flue dust to moderate the reaction were used. Details of the technology of application, the composition, the granulometry and the economies attained are given.—P. F.

Criticism of Methods of Calculating Heads for Steel Castings. G. K. Knyaginin. (*Lit.*

Proizv., 1957, (4), 24–25). [In Russian]. The author of this note describes the favourable results obtained at a foundry where the method of B. B. Gulyaev was adopted for calculating heads for rolling-mill roll casting.—S. K.

The Effect of Design Variables Upon Shrinkage Defects Under Bosses On Thin Plates. A. G. Fuller. (*B.C.I.R.A. J. Res. Dev.*, 1957, **7**, Oct., 54–67). Effects of variation in plate thickness, boss size, "gating ratio," and the position of the sprue relative to the casting upon sinking beneath bosses on thin plates were studied. The results are discussed on the basis of metal flow and temperature conditions within the casting. The author concludes that sinking increases when conditions are such that the heat content of the metal filling the mould is increased.—L. E. W.

Compressed-air Risers: Improved Yield and Quality in Steel Castings. D. R. Kononow. (*Iron Steel*, 1957, **30**, Oct., 489–491). The author describes the use of P.V.D. risers, in which compressed air is applied to the risers of a casting after the mould is filled. The method increases the yield of defect-free castings to 75–80%, and also improves the properties of the casting.—G. F.

Faster Removal of Giant Risers. (*Can. Metalw.*, 1957, **20**, Oct., 38). An oxygen cutting system is noted.

Materials for Core Formation. (*Fonderia*, 1957, **6**, Sept., 381–385). [In Italian]. The paper discusses traditional methods of core formation, shell moulding, the CO_2 process, and self-drying agglomerating processes. The advantages and disadvantages of the various methods are reviewed.—M. D. J. B.

Automatic Production of Foundry Cores. (*Fonderia*, 1957, **6**, Sept., 385). [In Italian]. A method is described by which foundry cores are dried by high frequency electric heating. The speed of the process which lasts only a few minutes results in considerable savings.

The Use of Binder "M" for Cores for Iron Castings. A. V. Zhuravlev. (*Lit. Proizv.*, 1957, (3), 25). [In Russian]. The use of a urea-base core binder has been successfully tested in an iron foundry and shown to increase the capacity of the core department and lead to considerable economies. Operating details are noted.—S. K.

Feed Box or Frame Box? H. Melle. (*Giessereitechn.*, 1957, **3**, Aug., 178–179). Two methods of constructing core boxes are described and compared. The first type, the "feed box," is used in Western Germany for cores of 300 × 300 mm and above, and has a rigid frame with inclined walls (10 to 15°) which is glued and screwed down to a baseplate. Loose adjustable sections are placed within the frame to support the piece. In the "frame box," used in Eastern Germany, the piece is supported by the walls and base, which cannot be subdivided, so that they must be removed as a whole to free the core. The use of "feed boxes" is advocated.—L. J. L.

Sealing Core Boxes Against Blow-By. R. L. Olson. (*Mod. Cast.*, 1957, **32**, Oct., 41–52). Protection against erosion by core blowers is illustrated and the insertion of protective dikes is described for numerous types of box.

Coloured Cores. P. Rastall. (*Found. T.J.*, 1957, **103**, Oct. 24, 482). A letter describing the addition of dyes to water glass for foundry core binding so that the age of the cores can be seen at once.

Introduction of Quick-Drying Mould Mixtures into Steel Foundry Work. P. G. Vinnichenko and I. I. Kutilin. (*Lit. Proizv.*, 1957, (3), 24–25). [In Russian]. The introduction of a quick-drying water-glass based mould-mixture at the Riga wagon works is said to have enabled the productivity of the steel foundry moulding shop to be increased, the surface quality of the castings to be improved, rejects to be cut and the productivity of the cleaning department to be raised by 15–20%.

Conversion of a Coke-Fired Core Drying Oven to Gas Firing. (*Ind. Gas*, 1957, **20**, July, 25–26). The process of conversion is briefly indicated and comparative costs are given.

The Application of High-Frequency Stoves to the Baking of Cores in the Foundry and the Modern Organisation of Coremaking. P. Fraison. (*Fonderie Belge*, 1957, July-Aug., 175–180). The use of dielectric heating for core baking is described and its advantages are summarised. The rationalisation of coremaking practice by the use of modern equipment is illustrated and briefly described.

Abrasion of Bentonite Moulds and Cores. J. Dlezek. (*Slévárenství*, 1957, **5**, (7), 193–197). [In Czech]. The abrasion of green moulding mixtures was studied by subjecting standard specimens to a stream of steel shot. The surface brittleness of bentonite moulds and cores depends upon the amount of bentonite and water in the mixture, on the time of air drying and on the intensity of ramming. The dependence of abrasion resistance on these factors was studied systematically, and ways and means of reducing brittleness are indicated. Optimum water contents were found to be rather higher than values currently favoured.

The Importance of High Frequency Drying in the Foundry. E. Walther. (*Giesserei*, 1957, **44**, May 23, 316–318). The principles and practice of high frequency drying are described. The effect of drying time and temperature on the bending strength of cores is given. The power consumption and costs of drying by H.F. heating are compared with conventional methods. The high frequency method shows considerable saving. A H.F. drying furnace is then described and its method of operation detailed. The use of plastic drying dishes makes further automation of core manufacture possible and reduces costs by up to 90%.

Some Characteristic Properties of Water-Glass as Bonding Agent for Moulding and Core Sands. H. G. Levelink. (*Metalen*, 1957, **12**, Oct. 31, 406–412). Compressive strength of mixtures has been measured as a function of gassing time and exposure to air and three-dimensional diagrams are given for a variety of conditions. The effects of $SiO_2 : NaO_2$ ratio, amount of solids and the addition of coal dust and clay are discussed and the practical importance of composition.

Moulding With CO_2. L. Romano and A. Dorfmueller jun. (*Foundry*, 1957, **85**, Oct., 104–107). Complete CO_2 sand moulds, use as localized facing and use for full facing, methods of gassing, mould washes, and the advantages and problems of the process are reviewed.

CO_2-Methods. D. V. Atterton. (*Gjuteriet*, 1957, **47**, Sept., 141–150; Oct., 157–166). A general account is given with a statement of advantages and limitations. A new theory of hardening is advanced and sand properties and preparation are reviewed. Gassing time, impurities, additions of pitch and coal dust and core collapsibility and other factors are dealt with. Gassing methods, models, core-boxes and production moulds are described, with experiences in the use of the carbon dioxide process in different types of foundries. Consumption of gas and sand recovery are included. (12 references).

The Present Applications of the CO_2 Process. L. Petrzela. (*Fonderie Belge*, 1957, Sept., 209–222). The principles of the CO_2 process are reviewed and the type and composition of moulding materials that can be hardened by the process are summarised. The techniques used to harden moulds and cores are then described in detail. Other aspects of the process discussed include the sands used in steel, grey iron and malleable iron foundries, mould defects and the regeneration of used sand.—B. C. W.

Hot Deformation of Moulding Sand. H. W. Dietert and T. E. Barlow. (*Mod. Castings*, 1958, **33**, Jan., 43–47). Hot deformation and its relationship to temperature and composition is reviewed. Effects of blend and additives are given up to 2000° F.

How to Cut Costs on Patterns and Cores. R. K. Sinclair and W. N. Richards. (*Iron Age*, 1957, **180**, Dec. 12, 132–134).

Epoxy Resins for Patternmaking. K. H. Coombs, M. van der Wende and D. Jepson. (*Eng. J.*, 1957, **22**, Nov., 56–60, discussion 60–62). A comprehensive review of materials and methods is given.

On the Chilling Action of Cast Iron. K. Otani. (*Tetsu to Hagane*, 1955, **41**, Sept., 990–992). [In Japanese.] Two theoretical relationships between time of solidification and depth of the solidified layer are examined, and are compared with experimental results.

More on Metal Flow in Molds. G. Ohira. (*Mod. Castings*, 1956, **30**, Aug., 28–29). Experiments on gating are described in which a mould fitted with electrodes was used so that the metal completed circuits as it flowed in. Suitable proportions of cross-sections of sprue, runner and gates are determined.

Core Blowing. A. M. Clark. (*Mod. Castings*, 1956, **30**, Oct., 41–56). An outline of the history, equipment for, components in, and new principles in carrying out the process. A Special Report, illustrated.

The CO_2 Process. (*Mod. Castings*, 1956, **30**, Aug., 33–48). **What North American Foundries Have Learned About CO_2.** (34–35). A general account of details of the process. **Survey of CO_2 Developments in Great Britain.** D. V. Atterton. (36–44). A more detailed survey is presented of the casting by this method of steel and non-ferrous metals. **Now They're Making CO_2 Shells.** T. E. Barlow. (45). Equipment of diaphragm type is being used for the CO_2 process. **How a Midwestern Foundry Makes CO_2 Cores.** F. M. Scaggs. (46–48). An illustrated account of work by Oklahoma Steel Castings Co. Inc.

Application of the CO_2 Process in the Production of Steel Castings. I. Rees. (*Foundry Trade J.*, 1957, **103**, Dec. 19, 723–726). Use in a jobbing foundry is described.

Updating the Hi-Temperature Story on Gray Iron Castings. C. F. Walton, F. R. Brotzen and J. F. Wallace. (*Prod. Eng.*, 1958, **29**, Jan. 20, 52–57). Tensile, compression and hot-hardness curves, creep, stress-rupture and fatigue data of grey iron, including alloy grey irons, are given, as well as other mechanical properties, thermal conductivity and corrosion by molten metals.

Continuous Rod and Tube Casting. T. E. W. Preston. (*Metalw. Prod.*, 1957, **101**, Dec. 27, 2303–2309). The Solicast process for iron and phosphor-bronze worked by Sheepbridge Alloy Castings Ltd. is described.

Designer's Guide for Investment Castings. (*Mach. Design*, 1957, **29**, Aug. 22, 133–134). Dimensional tolerances are discussed for steels and non-ferrous alloys on a general cost basis.

Stop—Look—Listen before You Try Shell Moulding. A. Woods. (*Mod. Castings*, 1957, **32**, Dec., 50–54). Differences from green sand practice are noted. Pattern plates, gating and feeding, cracking of moulds, shell cores, stack moulding and the use of shell core blowers are described.

Shell Cores for High Production. (*Can. Metalw.*, 1957, **20**, Nov., 37–38). A brief account of the advantages obtained in a Canadian foundry.

A Literature Review of Metal Penetration. A. E. Murton and S. L. Gertsman. (*Mod. Castings*, 1958, **33**, Jan., 37–42).

The Sulphurisation Resistance of Spheroidal Graphite Cast Iron at High Temperatures. H. Nakai. (*Tetsu to Hagane*, 1955, **41**, Sept., 997–998). [In Japanese]. Sulphurization resistance is determined for Swedish charcoal iron not containing copper, and Australian pig iron containing ~0·5% copper, each with and without additions of Mg (max. 0·4%) and Al (max.1·0%).—K. E. J.

VACUUM METALLURGY

Vacuum Technology. (*Report on Symposium of the Committee on Vacuum Techniques*, 1956, *Chicago*, 1957, pp. 234). **Problems Involved in Vacuum Arc Melting Furnaces and Development of these Furnaces at W. C. Heraeus GmbH, Germany.** H. Gruber. (182–189). The topics discussed are the stabilization of the arc, electrode feeder control, size of pumping system and accident hazards. **Vacuum Induction Heating.** J. H. Moore. (202–208). Successive designs and the latest 2200-lb furnace are described and the operation and effects of the latter are developed, giving gas contents and other steel properties and comparisons with air-melted samples. **Thermodynamics of the Vacuum-Induction Melting Process.** W. J. Pennington. (209–214). Various pure metals including iron, and oxides and nitrides, including those of iron, are

reviewed. Comparisons with air-melted materials are made.

Vacuum Melting. W. E. Britton, G. F. Eline jun., S. M. Evans jun., C. W. Gasque, A. P. Goldenberg, T. J. Perkins, D. C. Thompson and F. Witt. (*Report for Graduate School of Business Administration, Howard University*, 1957, pp. 136). A thesis; a review with historical introduction, a list of U.S. firms using the process, and a general account of methods, apparatus, and of the properties and uses of vacuum-melted steels and other metals, and a note on the economics of the process.

Vacuum Melting in the Steel Industry Today. W. W. Dyrkacz. (*J. Met.*, 1957, **9**, Dec., 1513–1516). The author discusses the development of vacuum melting in the steel industry, referring particularly to induction vacuum melting and consumable-electrode vacuum arc re-melting of steels at Allegheny Ludlum Steel Corp. The advantages and disadvantages of both methods are summarised. The processes are becoming established in the special steel field, where they can provide materials with improved metallurgical properties for critical applications.

Vacuum Melted Steel: Commercial Scale Production in Sheffield. (*Metallurgia*, 1957, **56**, Nov., 237–238). Messrs. G. L. Willan Ltd., Sheffield, operate a 56 lb. vacuum melting furnace, producing vacuum melted stock for remelting by precision casting foundries. Brief details of the installation and of the development of the firm are given.—G. F.

Vacuum Treatment of Steel. V. G. Speranskii. (*Metallurg*, 1956, (8), 12–15). An installation consisting of a cylindrical chamber of steel lined with chamotte with a domed cover is described. The chamber has a support for the ladle and is evacuated to 30 mm in 5–6 min, the whole process lasting 10–11 min. More powerful pumps would therefore be an improvement. Erosion of the nozzle by slag was observed and bricks resistant to basic slag should be used. The level of the slag rises 13–16 in. during "boiling," the greatest gas liberation being from transformer steel. Analyses are given showing the effects of treatment. C, S and gases are reduced and quality improved.

Vacuum Stream Degassing is New Tool for Steel Plant Engineers. K. C. Taylor. (*Iron Steel Eng.*, 1957, **34**, Oct., 142–144). The principles of vacuum casting are briefly discussed and equipment is described which it is claimed gives a reliable method for the reduction and control of gaseous inclusions in steel.—M. D. J. B.

Interest Grows in Steel Degassing. K. C. Taylor. (*Can. Metalw.*, 1957, **20**, Dec. 28). Vacuum treatment is briefly indicated.

Vacuum Sintering. Part I. Theory and Practice. H. H. Hausner. (*Prec. Met. Mold.*, 1957, **15**, Oct., 44–45, 88; Nov., 91–92, 94–95; Dec., 44–46, 69). The effects of the atmosphere are dealt with, mainly in non-ferrous compacts and cermet systems. The rarer metals are dealt with in particular.

What About Investment Cast Vacuum Alloys. F. K. Iverson. (*Mod. Castings*, 1956, **30**, Aug., 24–26). A review, mainly of the advantages of the process and future prospects.

REHEATING FURNACES AND SOAKING PITS

Construction and Operation of Soaking Pits. I. Construction of Soaking Pits. Y. Yazawa. (*Tetsu to Hagane*, 1955, **41**, Sept., 1019). [In Japanese.]—K. E. J.

Glass Baths for Heating Steel Extrusion Billets. O. Balestra. (*Met. Prog.*, 1957, **71**, Jan., 109–112). The Fiav Mazzacchera Co. of Milan has made considerable savings in fuel and maintenance costs by using a gas-fired molten glass bath instead of a salt bath for preheating steel billets for extrusion. The new type of bath is described and illustrated, and its advantages are summarised.—G. F.

Automatically Controlled Pusher-Type Soaking Pits in an Alloy-Steel Blooming Mill. J. Heimerl. (*Stahl Eisen*, 1957, **77**, Dec. 26, 1873–1877). An electrical–pneumatic control system for a gas-fired three-zone pusher-type soaking-pit for alloy steel ingots at Böhler Kapfenberg is described and illustrated.—T. G.

Distribution of Air Ratio and Flow of Gases in the [Soaking Pit]. S. Muramatsu. (*Tetsu to Hagane*, 1955, **41**, Sept., 1017–1019). [In Japanese]. Results are given for a two-way top-fired recuperator soaking-pit. Air flow ratios and analyses are given for stated positions at different levels in the furnace.—K. E. J.

Fuel Savings Through Design Changes in Box-Type Forge Furnaces. F. P. Merkle. (*Steel Proc.*, 1957, **43**, Nov., 637–639). A comparison of flat top and sprung roof furnaces is shown and the fuel saving by the flat roof type is discussed. The units were oil-fired.

The Re-heating of Ingots in Soaking Pits. (*Technique Moderne*, 1957, **49**, July, 366–369). Types of soaking pits are reviewed and their recuperators, refractories, heat requirements and control are considered.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

How To Get More For Your Metalworking Dollar: Heat Treating. (*Iron Age*, 1957, **180**, Oct. 24, 207–222). **I. Heat Treating Plain Carbon and Low Alloy Steel.** (208–211); **2. Pointers on Surface Hardening.** (212–214); **3. How To Heat Treat Gray and Ductile Cast Irons.** (215–216); **4. Tips on Heat Treating Stainless.** (217–219). The principles and practice of heat treating are reviewed, with a view to promoting useful and efficient treatment.

Heat Treating Practice in Russian Steel Mills. L. Wilson. (*Met. Prog.*, 1957, **71**, Jan., 116–121). From first-hand experience, the author describes the production equipment and operating techniques at the Russian steel plants at Magnitogorsk and Zaparochy. Both plants produce steel sheet, and the author pays particular attention to sheet rolling, annealing, and tinning.—G. F.

A Versatile Automatic Large Oven Furnace. J. N. Helfat. (*Steel Proc.*, 1957, **43**, Oct., 581, 589). A heat-treating furnace 6 × 6 × 6 ft inside dimensions heated by twin nozzle tunnel burners is described and some treatment cycles are given.

Industrial Application of Inert Gas-Fired Generators. (*Ind. Gas*, 1957, **20**, Oct., 6–9). Various installations for the production of inert atmospheres are mentioned, not for metallurgical purposes, with an account of the analysis of the mixtures.

The Calculation of Heat Transfer in Furnaces. F. Fitzgerald. (*Fuel. Soc. J.* 1957, **8**, 60–68). A review of existing knowledge on heat transfer from flames is presented, with particular emphasis on luminous radiation. For non-luminous flames, in a small-scale experimental furnace, a simple method of calculation is shown to give results agreeing very closely with measured heat transfer rates.—D. L. C. P.

The Refractory Tunnel Gas Burner. (*Mech. World*, 1957, **137**, Sept., 402–405). Design, characteristics, and use for localized heat treatment are described.

Rotary Retort Furnace, Duplex Quench Improves Case Hardening of Fasteners. W. Schmidt. (*Western Metalw.*, 1957, **15**, Oct., 43–45). A 4-stage heat treating line is described and illustrated.

Continuous Gas Carburizing: Two New Birlec Installations. (*Iron Steel*, 1957, **30**, Nov., 613). The Ford Motor Co. at Dagenham has recently installed two Birlec continuous gas carburizing installations of the gas-fired, double track type. Details of design and operation are given.—G. F.

Fundamental Investigation on Gas Carburisation and Bright Heat-treatment. M. Kawakami. (*Tetsu to Hagane*, 1955, **41**, Sept., 1049–1050). [In Japanese].—K. E. J.

Sintin—A New and Efficient Agent for Gas Carburising. A. T. Kalinin, M. N. Kunyavskii and A. Ya. Zaitseva. (*Metallovedenie Obrab. Met.*, 1956, **2**, Nov., 40–49). Sintin (or synthol) is a low-aromatic high-paraffin Fischer-Tropsch oil free from sulphur. Trials on carbon and low-alloy steels are described. In general paraffinic products give less soot and gas than aromatic, olefinic or naphthenic products.

A Study on Induction Hardening. I. K. Nagaoka. (*Tetsu to Hagane*, 1955, **41**, Sept., 1047–1048). [In Japanese.]—K. E. J.

Multi-Purpose Heat Treat. E. A. Schoefer. (*Met. Prog.*, 1957, **72**, Sept., 83–87). A system for heat treating relatively small tonnages of small parts of various types of steel and cast iron has been developed by International Harvester Co., using two in-and-out batch-type carbonitriding furnaces, a washer, unique arrangements of roller conveyors, and extensive use of high-alloy (type HT) castings. The system is described and illustrated.—G. F.

Nitriding of Large Forgings. C. W. Johnson. (*Met. Prog.*, 1957, **72**, Dec., 99–101). By means of special gas muffle furnaces, the National Forge Ordnance Co., Irvine, Pa., can nitride large crankshafts for Diesel engines. A brief description of the technique is given, and the improved properties of the crankshafts are discussed.—G. F.

Theoretical Considerations of the Oxidation and Decarburisation of Steels During Heat Treatment. P. B. Simpson. (*Fuel Soc. J.*, 1957, **8**, 32–43). Present knowledge on the effects of air-fuel ratio, temperature, alloying elements and sulphur on the oxidation and decarburization of steels is summarized. The kinetics of these reactions are also discussed.

Decarburization—How and Why. N. J. Grant. (*Mod. Castings*, 1956, **30**, Oct., 64–71). A general account of the defect occurring during heat treatment, hot-working, and during the cooling of castings. Microstructures are shown and the conditions under which they occur are discussed. For a given section size and cooling rate hypo-eutectoid steels decarburize more than hypereutectoid. The thinner the section the less the decarburization, rapid cooling would be advantageous if care were taken to avoid its other possible effects, and Cr, Mn, Si, W and Mo have no appreciable effects on the process.

Effect of Austenizing Conditions on Structure and Phase Transformation of Plain Carbon Steels. H. Borchers and G. Saur. (*Stahl u. Eisen*, 1958, **78**, Jan. 9, 40–46). The effects of annealing and transformation conditions on grain-size, phases and transformation points in the pearlite phase of hypo-eutectoid, plain carbon steels are reviewed and it is proposed to discriminate more precisely between austenite grain-size, and ferrite grain-size, and ferrite network-size. Studies on the effect of temperature on isothermal transformation are in agreement with results published by other workers.—T. G.

Isothermal Annealing Treatment for Alloy Steels. A. A. Hofman. (*B.H.P. Tech. Bull.*, 1957, **1**, Oct., 27–29). Tests on martensitic Cr stainless steel of B.S. 970 En. 56, (U.S. Type 420) are reported and the practical application of the process developed is outlined.

Annealing Furnaces in the Iron and Steel Industry. (*Technique Moderne*, 1957, **49**, July, 416–418). A brief review of the various types.

Continuous Annealing by Town Gas Introduced into Industry. (*Ind. Gas*, 1957, **20**, Sept., 16). The Velindre strip annealing furnace is referred to with temperatures and rate of passage.

Annealing of Steel Sheet. G. W. Form and E. B. Evans. (*Met. Prog.* 1957, **72**, Dec., 111–112, 142). The authors summarize the discussion which took place at a Symposium on annealing of low-carbon steel sheet, at the Case Institute of Technology in Oct. 1957. The three main topics were: the relative merits of batch annealing and continuous annealing; prepared furnace atmospheres; and the quality of the finished product.—G. F.

[A Continuous Annealing Furnace for Steel Tubing.] Z. Sudo. (*Tetsu to Hagane*, 1956, **41**, Sept., 1021–1023). [In Japanese]. The furnace is described, with sectional diagrams, and heating curves are given for tubing in the heating chambers at various speeds. The mechanical properties of several samples after annealing are listed.—K. E. J.

Stress Relieving of Welded Teeming Ladles. J. Finn and I. H. Wray. (*B.H.P. Tech. Bull.*, 1957, **1**, Oct., 22–26). A stress relieving

furnace for 300-t ladles and its performance are described.

Gas Fired Heat Treatment of Roller Bearings. (*Ind. Gas*, 1957, **21**, Nov., 26–27). Operations at British Timkin at Bilston are briefly outlined and illustrated.

Continuous, Rapid Heat Processing Makes High Strength, Seamless Oil Tubing. (*Western Metalw.*, 1957, **15**, Oct., 57–58, 60).. A continuous heat-treatment line for low-carbon steel pipes is described.

The O.N.E.R.A. Procedure for Skin Annealing in Gaseous Media Use of Bright Annealing for Steel and Heat-Resisting Alloys. P. Galmiche. (*Rech. Aéronau.*, 1957, July–Aug., 27–32). Difficulties met with in the heat-treatment of alloys susceptible to oxidation are described and the use of protective atmospheres is explained. The O.N.E.R.A. process is a chromium treatment producing a bright surface on steel and other metals and surface structures are illustrated and tests in the laboratory and in service are reported.

Practical Application of Bright Heat-Treatment of Steel. M. Kawakami. (*Tetsu to Hagane*, 1955, **41**, Sept., 1050–1052). [In Japanese.]

Induction Heating for Stress-Relieving Large Steel Cylinders. G. W. Seulen. (*Met. Prog.*, 1957, **71**, Jan., 126–130). Induction heating is coming more and more into use for the heat treatment of welded joints—preheating before welding, stress-relieving after welding, and normalizing. The author describes the application to welded circumferential joints in large steel cylinders, giving details of the equipment and operating technique.—G. F.

Relief of Residual Grinding Stresses by Annealing. H. R. Letner and A. B. Sauvageot. (*Met. Prog.*, 1957, **72**, Sept., 79–82). The authors show that residual grinding stresses can be relieved without softening hardened steel. The recommended procedure is to immerse the piece for 90 sec. in a salt bath at 500–600° F., and quench in water or agitated oil. This causes a 40–65% reduction in stress; raising the bath temperature to 650° F causes 80% reduction, but with a slight decrease in hardness.—G. F.

The Effect of Sub-Zero Treatment on the Hardness and Strength of Some Carburised Steels. M. Yamaki. (*Tetsu to Hagane*, 1955, **41**, Sept., 981–983). [In Japanese]. The steels are CM 3, 4, 6 and 7; SCM 21, SNC 21 and SNCM 24 (compositions given).—K. E. J.

Use of Isothermal Heat Treatment in France. G. Stempfel. (*Met. Prog.*, 1957, **71**, Jan., 100–102). The author describes the development and use of isothermal heat treatment in France, paying particular attention to martempering and to the compositions and uses of salts.—G. F.

The Production of Ferrite in Spheroidal Graphite Cast Iron by Heat-Treatment. J. Gittus. (*Iron Steel*, 1957, **30**, Nov., 603–607; Dec., 639–641). The author has studied some of the factors determining the ease with which a ferrite matrix can be produced in S.G. iron by heat-treatment. The usual heat-treatment involves both austenitization and ferritization. If the former is omitted, subsequent ferritization produces an undesirable sub-boundary structure. Ferritization from the austenitic condition is the recommended procedure.

Hardenability of Pearlitic Malleable Iron. R. W. Heine. (*Mod. Castings*, 1958, **33**, Jan., 48–52). A report of the A.F.S. Committee 6E. Hardenability tests on castings from 6 foundries, are reported and the results shown graphically. The curves can be used to estimate the response to quenching in water or oil.

Modern Quenching Techniques. O. E. Cullen. (*Steel Proc.*, 1957, **43**, Dec., 700–701, 704, 708–709). A table shows details of the usual treatments, austempering, martempering, full and modified marquenching, conventional oil and water and selection of quenching media is discussed. Graphic methods for selection and the appropriate cooling curves are given. Quench tank arrangements are shown. Various distortion and growth data are tabulated and a summary of the advantages of good quenching is added.

Quenching Oils. (*Mech. World*, 1957, **137**, Aug., 372–373). A review of quenching curves and the properties of oils, both organic and mineral base, is presented.

You Can Quench-Age Malleable Iron. C. A. Beiser and E. B. Evans. (*Mod. Castings*, 1956, **30**, Oct., 39). Tests on ferritic malleable are described, on specimens $\frac{3}{8}$in. thick heated at 1300° F for 10 min in a salt bath quenched or air cooled and aged at 80, 125, 350, 600 and 850° F for varying times. Hardness and tensile properties were improved without change in microstructure.

New Temperability Calculator—Accurate Estimating Replaces Guesswork. L. Jaffe and E. Gordon. (*Iron Age*, 1957, **180**, Oct. 24, 227–234). A method for determining the tempering treatment that will produce a desired hardness in fully quenched (martensite) steels is described. The hardness contributions of the following are determined from curves:—%C, Mn, Si, Cr, Mo, Ni; grain size: from this an approximate tempering temperature can be calculated. Correction factors are then applied to allow for the effect on tempering temperature of tempering time, % Mo and C.—D. L. C. P.

FORGING, DRAWING, STAMPING AND PRESSING

Precision Forging. H. L. Showalter. (*Steel Proc.*, 1957, **43**, Nov., 615–624, 645–646). A review of precision forging machines and their possibilities. Types, design and mechanisms, forging cycles, control and lubrication, horizontal machines and the classes of work produced are considered in some detail and typical forgings are shown.

Advances in European Drop Forging. T. Bishop. (*Met. Prog.*, 1957, **71**, Jan., 113–115). The author describes some of the recent advances in Europe in the field of drop forging. The three main topics discussed are the reduction of die wear, the design of gravity drop hammers, and the production of cored forgings.—G. F.

Forgeability Tests: Are the Results Reliable? P. M. Unterweiser. (*Iron Age*, 1957, **180**, Nov. 14, 153–156). The difficulties of measuring forgeability are considered, and the types of test in use are reviewed. The number of variables makes useful tests of general application difficult to establish. Three important variables are flow stress (or internal friction), ductility, and friction coefficient (or external friction).—D. L. C. P.

Study on the Hot Drawing of Steel Tubes. K. Sato. (*Tetsu to Hagane*, 1955, **41**, Sept., 1052–1053). [In Japanese]. The influence of the initial wall thickness of the tube on the change of thickness and on the diameter change is followed for a drawing temperature of 800° C and diameter reductions ($\Delta D/D_0$) up to 18%.—K. E. J.

Scrap in Deep Drawing Reduced 90%. C. K. Divers. (*Met. Prog.*, 1957, **72**, Sept., 88–91). Following excessive splitting in the deep-drawing of wheel discs and hub caps of brass, stainless steel, and steel strip, the author found that the extent of splitting correlated well with results obtained with an Olsen cup tester. The testing method is described and examples of its application are discussed.—G. F.

Factors Affecting the Swelling of Steel Bars in Cold Drawing. A. I. Kukhorev. (*Stal'*, 1956, (2), 181–182). The amount of swelling after passage through a cold die increases with carbon content. Factors that must be studied for deciding the dimensions of dies are given.

Spring Design—XXIX. W. R. Berry. (*Mech. World*, 1957, **137**, Sept., 398–401). The effects of shot peening are considered and stress distributions and residual stresses are plotted in detail. **XXX.** (Oct., 466–470). Effects on laminated springs are reviewed and the Almen test and its findings are explained. **XXXI.** (Nov., 514–520). In the concluding article scragging followed by shot peening is reviewed and fatigue tests on various Si-Mn steels are shown and treated mathematically, and examples on estimating the effects of peening are worked. Corrosion effects and the effects of plating and similar protective treatments are briefly considered.

Colour Dynamics for the Modern Wire Mill. A. S. Keshen. (*Wire Wire Prod.*, 1957, **32**, Dec., 1486–1487, 1527). Colour schemes for wire mill machinery, service mains, and especially hazardous or dangerous fittings are suggested.

Practical Slide Rule Method for Calculating Percentage Reduction in Area in Working and Testing of Rod and Wire. F. A. Mohrnheim. (*Wire Wire Prod.*, 1957, **32**, Dec., 1495–1497, 1522). Difference of diameter is converted to reduction in cross-sections, number of passes and die sequences, largest starting diameter, percentage draft per hole in equi-drafting, slippage and other relationships.

Production Speeded by Cold Extrusion. K. Sieber. (*Metalw. Prod.*, 1957, **101**, Dec. 13, 2215–2219). A review of German techniques. Wider application, new plant and the development of new cemented carbides have contributed. An automatic 4-stage press is described and steps in its operation are shown. The multiple die press and its possibilities with cemented-carbide press tools is outlined and the properties of the WC carbides indicated.

Ugine-Sejournet Extrusion Process: A Review. K. Kawamura. (*Tetsu-to-Hagane*, 1957, **43**, Aug., 826–848). [In Japanese]. A comprehensive review covers the plant, power requirements, various installations in operation, properties and constitution of various extruded metals, the various sections possible and examples of extruded parts. (19 references).–K. E. J.

ROLLING MILL PRACTICE

Anisotropic Properties of Rolled Steel and Experimental Analysis of Their Causes. M. Watanabe and Y. Ideguchi. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1956, **6**, Oct., 345–358). Tensile tests on specimens cut in various directions from the rolled sheet show little or no tensile strength variations but a marked increase in ductility in the direction of thickness. Alignment and shape of microscopic inclusions appear to be the causes of directionality in structural steels.

Baldwin Automatic Control System for a Rolling Mill. (*Machinery*, 1958, **92**, Jan. 17, 157–158). Equipment for a cold strip mill installed by D. F. Tayler Ltd., Birmingham, is described. It depends on bremsstrahlung radiation for its action and operates on steel, copper or brass. The source is ^{90}Sr.

Equipment of the Iron and Steel Industry: III. Rolling Mills. (*Technique Moderne*, 1957, **49**, July). **Continuous Wire Mills. The Works of Wendel at Joeuf.** J. Boulangé and M. Biau. (351–353). **The Continuous Wire Mill of the Société Metallurgique de Normandie.** L. Boulez. (354–357). **Measurement of Increase of Length in Cold Skin-Pass Mills.** (357). S.E.P.E.M.A. equipment is briefly described. **Merchant Mill of the Sidélor Works at Homécourt.** M. Simon. (358–360). **The 700 mm Rail Mill of the Micheville Works of l'Union Sidérurgique Lorraine (Sidélor).** M. Royer. (361–365). **The Rôle of Automation in the 720 Strip Mill.** G. Liégeois. (370–374). The furnace, conveyors, reducing and finishing train controls, and the winders are described. **The Montataire d'Usinor Works, Continuous Pickling Line and New Four High Skin-Pass Mill.** M. Mallet. (375–381). **The Control of Power in Modern Continuous Mills.** F. Lafay. (381–382). An account of the control network in a mill is presented. **The Cold Sendzimir Mill: Installed at the Isbergues Works of the Compagnie des Forges de Chatillon, Commentry et Neuves-Maisons. Its Electrical Equipment.** J. L. Ceyrac. (383–390). Full particulars of the drives are given. **Skin-Pass Mill with Preset Reduction.** P. Blain. (391–392). **Mechanised Thin Sheet Mills.** Y. Charet. (393–394). **Four High Reversible Mill of S.A.F.E. Annealing and Two-High Skin-Pass.** M. Jobard. (396–398). **The New Sheet Mill of the Longwy Works of the Société Lorraine-Escaut.** J. Friry. (402–406). **Auxiliary Installations at Rolling Mills for the Shearing, Ripping and Sorting of Thin Sheets**

and Tin Plate. J. Breuzet. (419–424). **Finishing Machines in Rolling Mills.** E. Goue. (431–433). A general review of apparatus used in the finishing of rounds and plates such as shears, cutters and saws. **Recent Improvements in Heavy Plate Mills.** J. Charles (434–436). Straighteners, coolers and cutters are reviewed.

Roll-Separating Force and Minimum Thickness of Cold-Rolled Strips. A. Tong and G. Sachs. (*J. Mech. Phys. Solids*, 1957, **6**, (1), 35–46). Plastic deformation in rolling is approximated by that of plane-strain compression between parallel plates. Determination of coefficient of friction and flow stress is included. Limiting conditions in cold rolling are also treated.

About the Sendzimir-Type Planetary Rolling Mill Stand. A. Valsovský. (*Hutnické Listy*, 1957, **12**, (12), 1083–1087). [In Czech.] It is shown by a calculation that the weight of the backup roll together with that of the bearings and 26 planetary rolls virtually equals the roll pressure. The pressure screws of the mill therefore exercise only very small forces on the rolls. The result was obtained by assuming properties for the material corresponding to those of a 0·2%C steel at 1150° C. The surprisingly small apparent roll pressure is associated with the impact type of deformation in this type of mill, which differs from the more continuous type of deformation in an ordinary rolling mill.—P. F.

On Characteristics of Various Pig Irons for Chilled Cast Iron Rolls. K. Otani. (*Tetsu to Hagane*, 1955, **41**, Sept., 992–995). [In Japanese]. Various data are given for two charcoal irons, two normal pig-irons, four electrical irons and two remelted irons. These include composition, gas analysis, thermal analysis curves and specific heats between 400° and 900° C.—K. E. J.

Electron Microstructure of the Work Roll for Cold Rolling. I. II. K. Gokan. (*Tetsu to Hagane*, 1955, **41**, Sept., 915–916; 916–917). [In Japanese]. I. A roll with bad characteristics for rolling has a coarse-grained structure of martensite and retained austenite; one with good characteristics shows a finer, more even structure with cementite. Electron microstructures of specimens held for various periods and quenched for spheroidization are shown. II. A time-temperature relationship is shown for dissolution of spherical carbide in quench annealing.—K. E. J.

New Advance in Rolling Mill Bearings: United Coke & Chemicals' New Product. (*Metallurgia*, 1957, **56**, Nov., 246). Details are given of the new reinforced synthetic resin bearing material "Orkot," developed by United Coke & Chemicals Co. Ltd. In certain instances the use of the new material doubles the life of bearings in steel rolling mills.—G. F.

Blooming Mill Controls. M. P. Rathbone. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 3, 19–25). Possible developments in automation are considered. The advantages of electric drives are discussed and the possibility of the automation of manipulator drives is referred to. Automatic screw-down control, punched cards, follow up control, and the possibility of producing a fully automatic blooming mill are reviewed. A recent Russian mill is then referred to.

New Bar Rolling Mill at the Works of Sanderson Brothers and Newbould Ltd. (*Machinery*, 1958, **92**, Jan. 10, 107–108).

Rational Roll Pass Design for Rails. V. P. Khlebnikov, M. D. Fradin and P. A. Chekhovskii. (*Stal'*, 1957, (12), 1103–1107). Perfecting of the roll pass design with a change in the shape of the grooves of a 36 in. stand and a gradual reduction in the number of trapezoidal grooves to two together with an improvement in rail quality confirms the possibility of using not more than three grooves for optimum rail pass design.—R. S.

New Merchant and Bar Mill Has Improved Lubrication System. (*Iron Steel Eng.*, 1957, **34**, Oct., 137–141). The article gives a brief description of 3 specially built mill lubrication systems to feed 475 gallons per min of extreme pressure ore of various viscosities to gears and bearings on drives of a new merchant bar and rod mill at the Atlantic Steel Co.—M. D. J. B.

Algoma's Combination Bar and Strip Mill. W. H. Mulfiur. (*Iron Steel Eng.* 1957, **34**, Oct., 73–81). The combination features of the mill were specially designed to develop in a limited market a flexible mill producing economically quality hot-rolled sheets, strip, skelp, plate and merchant bars. The mill consists of eleven horizontal stands and five edgers with the attendent twist trough, vertical coilers, hot flying shears and piler as well as a plate run-out line and shear. The mill has a capacity of approximately 20,000 tons a month.—M. D. J. B.

Billet Heating—New Johnstown Rod Mill. F. R. Pullen. (*Iron Steel Eng.*, 1957, **34**, Nov., 134–139). A new rod mill has been installed at the Johnstown plant of Bethlehem Steel Co. with a minimum of interference with operations. A description of the new mill is given and some of the problems encountered in its installation are described.—G. F.

Effects of the Mill Arrangements on the Properties of Mild Steel Wire Rods. T. Ohtake, N. Eguchi and I. Kimura. (*Tetsu to Hagane*, 1957, **43**, June, 637–642). [In Japanese.] A comparison is made between rods produced in a four-strand high-speed continuous mill and a semi-continuous mill (a combination of a continuous with a Garret mill), in respect of roundness, scale formation, mechanical properties and microstructure. The tensile strength of wire drawn from the rod produced in the first mill was superior.—K. E. J.

Comparison of the Advantages and Disadvantages of Machining and Grinding of the Grooves in the Rolls for Wire Rolling. I. Examination of Service Life of Machined and Ground Rolls. T. Palm. (*Stahl u. Eisen*, 1958, **78**, Jan. 9, 35–37). The studies were carried out on rolls for finishing 5·5 mm wire rod. Although the ground roll had a surface quality of 0·3 μ as measured by a Talysurf apparatus compared with 1·6 μ for the machined roll, there was no difference in roll roughness after rolling 2-t = 10,500 m. wire rod. **II. Economies in the Finishing of Rolls.** H. Warrol. (37–39). Ground rolls produce a better finish of the wire rods at the very beginning but there is no difference after a short time. When using hard rolls, grinding is usually more economic, in particular with respect to roll life, as the waste is lower in regrinding a worn roll than in machining.

Modern Four-High Universal Reversing Mill for Heavy and Medium Plate. W. Müllenbach. (*Demag News*, 1956, (146), 25–32). The mill erected for Ruhrstahl A. G. Henrichshütte, Hattingen, is described and illustrated with plan and many details.

Planetary Hot Mill: Plant and Practice at Habershon's. D. M. Potter. (*Iron Steel*, 1957, **30**, Oct., 475–482; Nov., 587–590). The planetary hot mill at J. J. Habershon & Sons Ltd. has been in operation more than a year and reached a stage of tangible success. The mill design and characteristics are described, and details are given of the planetary assembly, the heating furnaces, and the descaling unit. Finally, the operating procedure is discussed.—G. F.

30 Years of Development in Continuous Hot Rolling. (*United Effort*, 1957, **37**, 4th Quarter, 7). The 54 in. hot mill at Weirton is shown.

A Century of Progress with Steel. (*United Effort*, 1957, **37**, 4th Quarter, 4–6). A brief illustrated account, mainly of the continuous rolling mill.

Operation of a Canadian Strip Mill. R. J. Barry. (*Iron Steel Eng.*, 1957, **34**, Nov., 90–95). The author describes the hot strip mill of the Steel Co. of Canada Ltd. and analyses the causes of the steady increase in efficiency during the past few years. Between 1953 and 1956, the average production rate of the strip mill was increased by 46% without capital investment, and during 1954–56, production rate was increased by 30% without affecting mill time available for rolling plate. The increases are largely due to the application of a 3-pass rather than a 5-pass breakdown on certain slabs.—G. F.

Tests on a Four-High Reversing Cold Strip Mill. H. Bischoff and K. H. Spiller. (*Demag News*, 1956, (145), 12–22). Extensive measurements are reported on power requirements, strip tension, roll forces and gauge variations. Tables and graphs are given and the results are discussed.

Multiple Strip Processing Gains in Popularity. E. F. Boening. (*Iron Steel Eng.*, 1957, **34**, Oct., 146). A short description is given of a 2-strand anneal and pickle line now being erected in the U.S.A.—M. D. J. B.

Gauge of Strip Measured by Electro-Mechanical Device. (*Blast Furn. Steel Plant*. 1957, **45**, Dec., 1413–1414). An X-ray thickness gauge developed by the U.S. Steel Co. Applied Research Laboratory and capable of direct indication of the strip thickness is briefly described.—B. G. B.

The Influence of the Principal Metallurgical Variables on the Quality of Billets and on the Yield in Rolling Seamless Tubes. V. Friedrich. (*Hutn. Listy*, 1957, **12**, (12), 1077–1083). [In Czech.] A detailed analysis is made of the effect of process variables in the production technology of seamless tubes, largely on the basis of works experiments carried out in Czechoslovakia. Rolling from billets and ingots is considered; the Stiefel and Mannesmann processes are discussed. Basic converter steels as well as O.H. steels were used. For highest yields and best quality it is necessary to use O.H. steel, but other factors in production are also important. Neglect of these may result in low yields.—P. F.

Some Problems of the Manufacture of Seamless Stainless Steel Tubing by the Mannesmann-Plug Mill Process. S. Nakajima. (*Tetsu to Hagane*, 1957, **43**, June, 663–668). [In Japanese.] Recent developments in the process are discussed, with particular reference to its use for stainless-steel tubing and the technical problems, especially that of the piercing operation.—K. E. J.

New Seamless Tube Mill Uses Almost 600 Double-Enveloping Gear Reducers. (*Iron Steel Eng.*, 1957, **34**, Nov., 186–190). The new automatic push-button seamless tube mill of Mannesmann Tube Co. extensively uses individualized motor-reducer drives, with double-enveloping worm gearing. Experience with the mill has indicated that these reducers ensure maximum load-carrying ability, maximum life, and minimum service troubles. Details of the installation are given.—G. F.

D-C Mill Motor Standards: A.I.S.E. Standard No. 1. (*Iron Steel Eng.*, 1957, **34**, Nov., 141–144). This is a revision (Sept. 1957) of the AISE Standard on D.C. mill motors, and adds three new larger frame sizes. Ratings, dimensions, back axle details, and tolerances are quoted.—G. F.

Steelworks Auxiliaries. S. A. G. Emms and G. F. J. Morgan. (*Elect. Rev.*, 1958, **162**, Jan. 24, 161–167). Roller tables, screwdowns, slab shears and hot coilers are reviewed.

Roll- and Pulley-Type Straightening Machines for Round Bars, Tubes and Sections. H. Wedl. (*Stahl u. Eisen*, 1957, **77**, Dec. 26, 1895–1897). The required bending moments of straightening machines are derived and the principles of a number of machines of the roll- and pulley-type for rounds, tubes and sections discussed.—T. G.

MACHINERY FOR IRON AND STEEL PLANT

Mobile Cranes for the Steel Industry. (*Brit. Steel.*, 1957, **23**, Dec., 386–387). An illustrated account of a demonstration of mobile handling equipment by Steels Engineering Products, Ltd. at Sunderland.

A Sixty Tons Capacity Erection Crane. O. L. Towndrow. (*B.H.P. Tech. Bull.*, 1957, **1**., Oct., 10–17). The crane was used in reconstructing the No. 2 blast furnace at Newcastle N.S.W.

Trends in Electrification and Automation of Iron and Steel Processes. W. E. Miller. (*Iron Steel Eng.*, 1957, **34**, Oct., 83–94). This paper describes electronic devices of the remote position control type used in all departments of iron and steel works in the U.S.A. Equipment in materials handling installations, at blast furnaces, in O.H. shops and at a variety of rolling mills is described.

Steelworks Supply and Distribution [of Electric Power]. J. E. McCartney. (*Elect. Rev.*, 1957, **161**, Dec., 1149–1152).

Operation of the Power System at Fairless Works. G. A. Goetz. (*Iron Steel Eng.*, 1957, **34**, Oct., 110–116). This paper describes the equipment used in the Fairless Works power system and its operation in parallel with the public utility to assure the most economical use of purchased and generated power consistent with the mill operating practices.

Recent Applications of Hydraulics to Steel Mill Drives. C. R. Taylor. (*Iron Steel Eng.*, 1957, **34**, Oct., 100–107). The author discusses the advantages of fluid power transmission. The steelworks applications described are for mill drives, hydraulic transmission on drop hammers and ingot handling manipulators and fall into the categories of gear, vane, piston and screw type units.—M. D. J. B.

Fire Resistant Hydraulic Fluids. H. R. Iker. (*Iron Steel Eng.*, 1957, **34**, Nov., 145–147). The author gives details of different types of fire-resistant hydraulic fluids. He emphases that in applying them, it is essential to know the limitations of the particular fluid with regard to the system in which it is installed. Factors to be considered are hydraulic pump design, temperatures involved, and other operating conditions.—G. F.

WELDING AND FLAME CUTTING

Studies of the Weld Heat-Affected Zone of T-1 Steel. E. F. Nippes, W. F. Savage and R. J. Allio. (*Weld. J.*, 1957, **36**, Dec., 531s–540s). It is shown that rapid cooling after welding has little effect on the impact performance of T-1 steel. The effects of slow cooling rates were studied and thermal cycles were worked out and simulated for several points in the heat-affected zone. Impact properties were determined and correlated with structure and thermal analyses and dilatometry were also used. Slow cooling was found to reduce notch toughness and conditions for obtaining satisfactory values are given.

Weldability of ND Steels. L. Reeve. (*Brit. Welding J.*, 1957, **4**, Sept., 425–432). Weldability tests are described which have been carried out on a series of C–Mn steels, also ND steel specified under B.S.S. 2762 (1956). CTS and Battelle cracking tests were made. The results obtained conform more to British carbon equivalent formula than to Battelle formula for weldability.—U. E.

The Experimental Determination of Bonding Temperature. G. Blanc and R. D. Wasserman. (*Welding J.*, 1957, **36**, Sept., 419s–422s). The bonding temperature was measured by a graphic method. In the case of the three filler metals studied (Cu–Zn + Ag; Cu–Zn–Mi + Ag, Cu–Zn–Ag–Cd), it was ascertained that the bonding temperature is considerably lower than the solidus of the filler metal.

Why Radiograph Welds? R. M. Robb. (*N.Z. Eng.*, 1957, **12**, Sept., 15, 319–322). The viewpoints of the design engineer, customer, contractor and welder are considered. Welding standards are discussed and the general nature of radiographic testing is expounded.

Effect of Time After Deposition on Hydrogen Content and Mechanical Properties Of Covered-Electrode Weld Metal. J. Colbus. (*Welding J.*, 1957, **36**, Nov. 489s). Abstract of a paper in *Jnl. Soudure*, 1956, **46**, 277–283, showing that the hydrogen content depends on the speed of welding.

Stress Relieving of Weldments. E. R. Parker. (*Welding J.*, 1957, **36**, Oct., 433s–441s). An extensive review of the origin, nature and effect of residual stresses and stress relief treatments on the performance of welded structures is given. (23 references).

And Now, Digital Flame Cutting. British Oxygen Gases and Ferranti Ltd. (*Metalw. Prod.*, 1957, **101**, Dec. 6, 2177–2179). A prototype computer-controlled flame-cutting machine has been demonstrated. It is intended for shipyard use. The control system is described.

Automatic Flame Profiling of Plate in Shipyard Practice. W. H. Pearse and R. R. Sillifant. (*Weld. Met. Fab.*, 1957, **25**, Dec., 461–468). The development of ship forms and the optical plate marking system are outlined. Machine tool control methods are then considered and fully automatic control of oxygen cutting machines is described. An experimental machine is mentioned and yard lay-out and the storage and conveying systems discussed. Punched tape is used.

MACHINING AND MACHINABILITY

Temperature Rise of Workpiece during Metal Cutting. K. Nakayama. (*Bull. Faculty Eng. Yokohama Nat. Univ.*, 1956, **5**, 1–10). The temperature rise of a workpiece during turning was measured, and the effects on the cutting process are discussed. Contact with constantan wires was used to measure temperature rise and a SAE 1040 steel tube was turned with a cemented carbide tool with 5° relief angle and without cutting fluid. Theories are summarized and compared with findings.

Study of High Speed Machining. VIII. Effect of Tool-Chip Contact Area on Tool Life. H. Takeyama and E. Usui. (*J. Mech. Lab. Japan*, 1957, **11**, Nov., 185–188). [In Japanese]. Rake angle is also studied. Contact area is shown to have a very important influence on tool life and at optimum contact area the tool life may be increased up to 140%. Rake angle plays a part both on its own account and in relation to contact area. **IX. Effect of Tool Grinding Conditions on Machining Performance.** (189–193). The effect of tool grinding conditions is represented by an equation in terms of shear and rake angles, contact area and area of cut. The variation of contact area is shown to be independent of so-called coefficient of friction of the rake face, and to be influenced by affinity between the rake face and the chip which depends upon the condition of the face produced by grinding conditions and is independent of temperature.

Turning Operations on High-Temperature Alloys. A. B. Albrecht. (*Machinery*, 1957, **91**, Dec. 20, 1431–1434). Compositions of austenitic, age-hardenable and Co alloys are given with speeds and feeds recommended. Tool gauges are also tabulated and coolants used and power required are also indicated.

Some Properties of Free-Cutting Steel. Low Carbon Resulphurised Steel and Rephosphorised Steel. T. Onishi. (*Tetsu to Hagane*, 1955, **41**, Sept., 973–974). [In Japanese]. The cutting resistances of the two types of steel are compared with that of plain carbon steel, after annealing, normalizing and cold-drawing. Curves of impact value against temperature are given for the same steels after the three treatments. **Medium-Carbon Resulphurised Steel.** (974–976). Curves of impact value against temperature are given for medium-carbon resulphurized steel and for plain carbon steel, in the annealed, normalized, quenched and tempered, and cold-drawn conditions. Cutting resistances of these steels are compared with those of the corresponding low-carbon steels, in the same 4 conditions.—K. E. J.

Motor Makers Discuss Aircraft Construction. J. L. McCloud. (*Metal Progress*, 1957, **72**, Dec., 77–81). The advent of strong steel and Ti sheet materials for aircraft construction introduces new problems in dimensional tolerances and in their machining, bonding, and plating. These problems are discussed and particular attention is given to electrolytic grinding and milling, and to metallizing in vacuum to avoid hydrogen embrittlement.

Residual Stresses from Machining Operations. E. K. Henriksen. (*Steel Proc.*, 1957, **43**, No., 633–635, 639–641; Dec., 698–699, 710–711). A brief historical introduction is followed by an account of the origin of the stresses, their mechanism of formation, data for single point tools in relation to rake angle in carbon and stainless steels. The effects of milling cutters and grinding stresses are then reviewed in low and high C steels and their origin is discussed. (34 references).

French Developments in Sintered Ceramic Cutting Tools. L. Gion and L. Perrin. (*Machinery*, 1957, **91**, Dec., 20, 1420–1430). Production and performance, wear, and the effects of feed rate and depth of cut, shock, grade of steel or other material, tips, tool holders and costs are all reviewed.

Ceramic-Oxide Cutting Tools. R. M. Gill. (*Machinery*, 1957, **91**, Dec., 6, 1341–1346). Their development, properties and advantages are reviewed, recommendations for their use are given and test results are quoted. Forms of breakdown are illustrated.

The Re-servicing of Carbide Tools. (*Machinery*, 1958, **92**, Jan. 17, 136–154). A careful account of the grinding or spark erosion of carbide tips and of the characteristics and performance of the tools of various shapes and finishes. Care of the diamond wheels is stressed.

On Shot for Peening. III. Effect of Shot Hardness on Residual Stresses. K. Kamishohara. (*Tetsu to Hagane*, 1955, **41**, Sept., 969–970). [In Japanese.] The influences of shot hardness on the maximum residual stress and depth of cold working are traced, and surface finish profiles of the peened specimens are shown.—K.E.J.

On the Shot for Peening. V. Effect of Shot on the Archeight, Coverage and Roughness. M. Uchiyama and K. Kamishohara. (*Tetsu-to-Hagane*, 1957, **43**, Aug., 822–825). [In Japanese.] The S.A.E. methods for evaluating the quality of shot-peening are tested, and some conditions where the formulae are not valid are explained. "Reflecting-surface" peening is discussed. (16 references).

Grinding Wheels; Their Selection and Application. A. G. Gardner. (*Mech. World*, 1957, **137**, Nov., 486—492). A comprehensive review of types, materials, purposes and the principles of selection for the various operations, is given.

A New Spark Machine Technique. J. D. Shoemaker. (*Machinery*, 1958, **92**, Jan. 10, 74–76). Impact extrusion die finishing by Lockheed Aircraft is described. A yellow brass electrode is used.

Russians Discover Spark Cutting. (*Met. Prog.*, 1957, **71**, Jan., 121–125). This article describes the process of cutting, forming, and hardening of metals by electric spark techniques, giving information from a number of recent Russian publications. It deals with the shaping tool, working methods, the production of dies for press tools, and the toughening of surfaces for superior wear resistance.—G. F.

CLEANING AND PICKLING

Pre-Treatment of Sheet Metal for Enamelling. A. Petzold and M. Betzer. (*Ceramics*, 1957, **9**, Oct., 38–41, from *Glas-Email Keramo-Techn.* 1957, **7**, 284). Bright annealing in protective atmospheres is described and laboratory trials are reported on single-coat enamelling.

Barrel Tumbling: How to Get Best Results. R. W. Fitch. (*Products Fin.*, 1957, **22**, Oct., 28–34, 36, 38, 40, 42). Apparatus, abrasives and cleaning compounds are reviewed and the choice of media and their uses is indicated. Barrel speed, rinsing and drying, typical jobs and job analysis and the screening of finished parts are outlined.

Barrels of Savings. R. Hill. (*Western Metalw.*, 1957, **15**, Sept., 49–52). A review of barrel finishing and the operations it can be used to carry out. Uses at the Criterion Machine Works, Calif., and at Lockheed Aircraft, Burbank, Calif., are surveyed.

Weirton Steel Places Additional New Facilities into Operation. (*Iron Steel Eng.*, 1957, **34**, Nov., 148–155). Weirton Steel Co. has recently placed in operation a new continuous cleaning and annealing line in the tinning mill and a new continuous coil galvanizing line in the sheet mill. Details are given of the two new installations and of other recent improvements.—G. F.

Continuous Surface Pretreatment Processes with Particular Reference to "Nitec" Sheet for Vitreous Enamelling. W. H. F. Tickle and D. A. Winton. (*Met. Fin. J.*, 1957, **3**, Nov., 453–455, 464). Nitec sheet has a protective coating of nickel and zinc.

Why Metallurgy of Iron Shot is Important. A. M. Hall. (*Iron Age*, 1958, **181**, Jan. 16.

84–86). The microstructure, composition and shape of shot for blasting are discussed.

Blast Cleaners Treat Parts in Line. (*Iron Age*, 1957, **180**, Dec. 26, 52–53). The arrangement of Wheelabrator units in the General Motors Saginaw Division is described.

Mechanical Blast Cleaning of Wire Rods. K. J. Sorace. (*Wire Wire Prod.*, 1957, **32**, Dec., 1478, 1520). Procedure at Lamson & Sessions Co. works is briefly considered.

Handling Unit Speeds Blast Cleaning Cycle. (*Iron Age*, 1957, **180**, Nov. 14, 168). A barrel abrasive system with mechanical loading is briefly described.

From Hot Rolled Rod to Finished Wire Through the Process of Mechanical Blast Cleaning. G. D. Dill. (*Wire Wire Prod.*, 1957, **32**, Dec., 1473–1476, 1528). A description of the various types of blast-cleaning lines is given with estimates of costs.

Mechanical Descaling and Drawing of Mild Steel Rods. L. Marsden. (*Wire Prod.*, 1957, **6**, Oct., 5,7–9, 11–12). A Staff School Award Paper. The lay-out, pay-off, soaper and drawing machine, the drawing process and lubricants are described with diagrams. The important points are collected in a summary relating to dimension and speeds.

Surface Preparation for Protective Linings and Coatings Used in Critical Service. S. J. Oecksle, jun., and K. G. Le Fevre. (*Eng. Digest*, 1957, **18**, Nov., 485–486). Design is briefly considered and sand blasting, etching and cleaning are reviewed.

PROTECTIVE COATINGS

The Protection of Steel Structures in Salt Atmospheres. H. E. Bright. (*Corros. Techn.*, 1958, **5**, Jan., 17–21). Exposure tests at Sydney are reported on steel with various pretreatments, paint systems and Zn and Al spray coatings.

Motor Generators for Electroplating. H. E. Head. (*Products Fin.*, 1957, **22**, Oct., 44–48, 50, 52; Dec., 54–58, 60, 62).

Electrodeposition Stress: Part 3. Y. Shibasaki. (*Bull. Faculty Eng. Yokohama Nat. Univ.*, 1954, **3**, 76–95). Calculations on successive infinitesimally thin Cu layers are shown and discussed.

Peening Cuts Stresses in Plated Parts. W. W. Safee. (*Prod. Eng.*, 1957, **28**, Dec. 9, 92–83). Shot peening removes stresses produced by plating, especially by hard Cr plate; it is also useful before carburizing, where fatigue life may be increased by 30%, and for coil springs, cold-straightened shafts, decarburized and stress-corroded parts and for metals after grinding.

Some Properties of Chromium Deposited from an Electrolyte Containing Fluoride. N. E. Ryan, F. Henderson, S. T. M. Johnstone and H. L. Wain. (*Nature*, 1957, **180**, Dec. 21, 1406–1407). Fluoride baths work at lower temperatures and at higher current efficiencies than sulphate baths. It is shown that the products do not differ greatly in purity and in properties, though the small differences found are discussed.

Hard Chromium Plating of Large Extruding Dies at Normal Temperature. M. E. Gol'dshtein. (*Stanki Inst.*, 1957, **28**, (4), 34–35). Baths containing NH_4F instead of H_2SO_4 are developed with low current density and high throwing power.

Surface Finishing Formed Steel Shapes. G. H. Poll, jun. (*Products Fin.*, 1957, **22**, Dec., 42–47). Bright chromium finishing of steel stove tops is described. Plating and cleaning operations are described. Satin chromium finishing and the painting of plated decorative strips are also noted.

Polyvinyl Chloride Tape in Corrosion Mitigation Programmes. A. C. Kilberg. (*Corros. Techn.*, 1958, **5**, Jan., 10–12). Applications to gas mains and other buried steel pipes are noted.

Outdoor Storage Tanks Protected by Vinyl Coating. (*Products Fin.*, 1957, **22**, Oct., 24–25). Tanks holding aqueous ammonia are thus protected.

Plastisol Coating of Plating Racks and Tanks: A Job for Specialists. E. A. Blount. (*Products Fin.*, 1957, **22**, Nov., 34–42).

The Production of Enamelling and Zinc-Coated Steel Sheets. (*Met. Fin. J.*, 1957, **3**, Oct., 401–407). An illustrated account of the visit of Enamelling Conference Delegates to John Summers and Sons, Ltd.

A Survey of Abrasion Resistance Tests for Vitreous Enamels. J. A. Clarke. (*Met. Fin. J.*, 1957, **3**, Oct., 408–412, 426).

The Application of Vitreous Enamel by the Electrostatic Process. S. Hallsworth. (*Met. Fin. J.*, 1957, **3**, Nov., 449–452, 464).

Painting Structural Steel. G. M. Hamilton. (*South African Mech. Eng.*, 1957, **7**, Oct., 55–59; discussion, 59–69). A review of pre-treatment, primers and finishing coats, and breakdown processes is given.

POWDER METALLURGY

Superfine Iron Powders. M. W. Freeman and J. H. L. Watson. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 112–124). The authors discuss the production of certain superfine powders of iron and other metals, and give details of their applications and of their metallurgical and other properties. The particle size involved is 0·01–0·05 microns.

The Sintering of Iron-Copper-Carbon Compacts. P. U. Gummeson and L. Forss. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 131–137). Fe-Cu-C compacts have high strength and provide for very good dimensional control under adverse atmosphere conditions. The disadvantages are hardness and brittleness. Some of the relevant facts about the Fe-Cu and Fe-C systems are reviewed, and the properties of compacts with different Cu contents are considered.—G. F.

Panel Discussion on Presses for Compacting Metal Powder. (*Proc. Metal Powder Assoc.*, 1957, (1), 58–77). J. D. Shaw. **Single Punch, Simple Motion Presses versus Multiple Punch, Multiple Motion Presses, Advantages and Fields of Application of Each.** J. J. Kux. (58–61). **Dual Motion and Multiple Motion Presses.** G. Karian. (61–65). **Compacting Presses.** B. B. Belden. (66–69). **Watson-Stillman 6-125 Press.** D. G. Cameron. (69–70). **Fully Mechanical Automatic Presses to Accommodate a Floating Die Set System.** W. A. Gort and O. Assmann. (70–73). **Metal Powder Presses.** C. C. Sutinen. (73–77). Details are given of some of the various types of presses available for the compacting of metal powders. Both American and European designs are considered.—G. F.

Activated Sintering. M. Eudier. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 5–9). Activated sintering involves the use of a highly reactive vapour to accelerate the complete sintering of the metal particles. The author shows how the practice reduces considerably the wide variations which can occur in tensile and impact strengths, and increases the field of application of powder metallurgy.—G.F.

The Mechanism of Sintering. "Recorder." (*Met. Ind.*, 1957, **91**, Dec. 6, 481–482). A review with special reference to the work of Alexander and Balluffi on copper.

Powder Metallurgy in the Manufacture of Roller Chains. C. L. Richards. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 138–141). The Whitney Chain Co. uses powdered metal components in the manufacture of roller chains. The reasons for the adoption of these components are discussed, and the improvement in chain properties is indicated.

Fiber Metallurgy. C. H. Sump and W. Pollack. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 42–48). The production of fibre metal material in continuous sheet form, by methods similar to those used in the paper industry, is making a low cost production method available for producing strong porous metal products. The processing steps used in its manufacture are described.—G. F.

Current Developments in the Rolling of Both Ferrous and Non-Ferrous Powders. J. D. Shaw and W. V. Knopp. (*Proc. Metal Powder Assoc.*, 1957, (**1**), 33–41). The authors discuss the current status of rolling of metal powders. The basic principles involved are considered, and typical properties of rolled powder metal strip are given.—G. F.

FERRITES, CERMETS AND CARBIDES

The Crystal Structures of a New Group of Ferromagnetic Compounds. P. B. Braun. (*Philips Res. Rep.*, 1957, **12**, Dec., 491–548). The compounds are complex Ba, Ba-Zn and Ba-Co ferrites.

Characteristics and Present Requirements of Ferrites. R. D. Harrington. (*Proc. Metal Powder Assoc., 13th Annual Meeting, May*, 1957, *Chicago*, **II**, 177–188).

The Thermal Expansion of Ferrites at Temperatures Near the Curie Point. W. R. Buessem and A. Dorf. (*Proc. Metal Powder Assoc., 13th Annual Meeting, May*, 1957, *Chicago*, **II**, 196–204).

Bonding Ceramics to Metals. A. E. Williams. (*Ceramics*, 1957, **9**, Nov., 20–25; Dec., 26–30). Applications in the electrical industry and to pipe systems and filters are reviewed. Pipe couplings are included.

Magnetic Properties of the $FeTiO_3$-Fe_2O_3 Solid Solution Series. Y. Ishikawa and S. Akimoto. (*J. Phys. Soc. Japan*, 1957, **12**, Oct., 1083–1098). **Magnetic Properties of the $NiTiO_3$-Fe_2O_3 Solid Solution Series.** Y. Ishikawa. (*J. Phys. Soc. Japan*, 1957, **12**, Oct., 1165).

PROPERTIES AND TESTS

Fundamentals of Scale Model Experiments. W. O. Philbrook. (*J. Met.*, 1957, **9**, Oct., Section 1, 1353–1358). Scale-model and pilot-plant experiments are based on the principles of similarity, and certain dimensionless parameters must be the same for both model and full-size equipment. The author discusses several applications of models, and points out that a careful analysis must be made to determine which natural laws are the most critical, and which may either be neglected or a correction made from experience with other models.—G. F.

Growths of Iron Alloy Single Crystals from the Melt. R. C. Hall. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**, *J. Met.*, 1957, **9**, Oct., Section 2, 1267–1268). The author describes an apparatus developed to grow single crystals of alloys of high hardness and high melting point. The nature of single crystals of Al-Fe and Si-Fe alloys is outlined.

On the Classification of Steels by Pellets. E. Kawada. (*Tetsu to Hagane*, 1955, **41**, Sept., 917–918). [In Japanese.]—K. E. J.

The Adiabatic Vacuum Calorimeter at 600–1600° C. Specific Heat of Titanium, 44% Cr–Fe Alloy, and a Low-alloy Steel. I. Backhurst. (*J.I.S.I.*, 1958, June, **189**, 124–134). [This issue].

Influence of Carbon on the Properties of 18-4-1—Type High-Speed Steel. N. Yamanaka, K. Kusaka and M. Kitahara. (*Tetsu to Hagane*, 1957, **43**, July, 720–725). [In Japanese]. Results are given for the influence of carbon content on the critical temp., M_s point, quenched and tempered hardness, retained austenite, dimensional changes, toughness and mechanical properties at high temperature.—K. E. J.

A Study of Rivet Steel. K. Horikawa. (*Tetsu to Hagane*, 1955, **41**, Sept., 970–972). [In Japanese]. For six steels (SV34, SV41K, SV41R and three high-tensile steels), of given composition, mechanical properties are given for the round bar, the rivet and the rivet after rivetting.—K. E. J.

METALLOGRAPHY

A New Record-Keeping System for Metallographic Laboratories. J. R. Driear. (*Met. Prog.*, 1957, **72**, Dec., 89–91). The author describes a simple numbering method for photographs, specimens and all pertinent information relating to laboratory metallographic investigations. By relating all items to a key request number, record-keeping is simplified and more efficient.—G. F.

Cross Sectioning of Whiskers. S. S. Brenner and C. R. Morelock. (*Rev. Sci. Instr.*, 1957, **28**, Aug., 652–653). A method of mounting in a polyester for sectioning is described. Sections of Fe and other whiskers are shown.

Etchant for Stainless Type 403 Forgings. R. D. Buehheit. (*Met. Prog.*, 1957, **72**, Sept., 95–96). To show up flow lines and macro-structure in Type 403 martensitic stainless steel forgings, the author has developed an electrolytic etch using a bath of 20 ml ethylene glycol, 20 ml HNO_3, and 100 ml ethyl alcohol. The procedure is outlined and a typical result illustrated.—G. F.

Stability of A.I.S.I. Alloy Steels. A. B. Wilder, E. F. Ketterer, and D. B. Collyer. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1176–1181). The authors have studied the changes in microstructure observed in typical A.I.S.I. constructional alloy steels in the welded and unwelded conditions after exposure for 34,000 h at temperatures of 900–1200° F. The tensile and creep rupture properties after exposure for 10,000 h are also evaluated. The steels are compared with those now used for piping and elevated temperature service.

Cross-Rolling and Annealing Textures in High-Purity Iron. H. Hu. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1164–1168). Using an X-ray Geiger counter spectrometer, the author has determined the deformation and annealing textures of cross-rolled high-purity iron specimens. The main deformation texture is (100) [011] and is retained in partial recrystallization, whilst the minor deformation texture components are replaced by new orientations. Complete recrystallization develops a rather complex and widely scattered texture, which could be derived from the deformation texture components by rotations around (110) poles. The tendency for recrystallization is discussed.—G. F.

Contribution to the Technology of Cast Austenitic Corrosion-Resistant Nickel-Molybdenum Alloys. W. Gödecke. (*Werks. Korr.*, 1957, **8**, Oct., 580–587). The effects of impurities on the microstucture of Ni-Mo-(Cr) alloys of the Hastelloy B and C types have been studied. Commercial alloys of the B type, with about 32% Mo, usually contain appreciable quantities of a hard Ni-Mo compound. The formation of this compound is favoured by the presence of iron, silicon and carbon but homogeneous alloys can be obtained by keeping these elements down to low limits. The pure alloys work-harden much less rapidly than the commercial material. Electrochemical studies showed that the C alloy has a tendency to passivity, whereas the B alloy has not.—J. C. H.

Metallographic Study on the Brittle Rupture of a Steel at Low Temperature. I. N. Koda. (*Tetsu to Hagane*, 1955, **41**, Sept., 922–923). [In Japanese]. The relationship between cracking and grain boundaries is shown for specimens ruptured at $-9{\cdot}5°$ and $-19°$ C, and also the relationship between cracking and pits.—K. E. J.

Investigation of Grain Boundary Phase in Stainless Steel. C. C. Clark, J. R. Mihalisin and K. G. Carroll. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1210–1211). Using X-ray and electron micrograph techniques, the authors have investigated the grain boundary phase observed in a 25% Cr–20% Ni stainless steel containing 0·001% B. It is suggested that the boron acts as a powerful catalyst, the boro-carbide (Cr, Fe)$_{23}$ (B, C)$_6$ first precipitating and in turn nucleating the carbide Cr_2C_{26}.—G. F.

CsCl-Type Ordered Structures in Binary Alloys of Transition Elements. T. V. Philip and P. A. Beck. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1269–1271). Using X-ray diffraction, the authors show that the body-centred-cubic disordered structure in a VFe alloy, formed on quenching from 1250° C, is transformed on annealing at 600° C into a CsCl-type ordered structure before practically any stable σ phase is formed. The stability of the structure increases from CrFe to VFe to TiFe, indicating that the A-B bond increases in strength, as compared with the A-A and B-B bonds. This is accompanied by increasing brittleness, increasing lattice contraction, and the disappearance of ferromagnetism.—G. F.

Distribution of Boron in Gamma Iron Grains. R. M. Goldhoff and J. W. Spretnak. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1278–1283). The authors have studied the distribution of B in γ-iron grains, examining the grain growth in high-purity Fe-C and Fe-C-B alloys, measuring X-ray parameters on Fe-B alloys as a function of temperature, and metallographically testing for the boron constituent. They conclude that B undergoes positive adsorption to γ-iron grain boundaries and that the temperature coefficient of adsorption is positive.—G. F.

Electron-Microscopical Structure of Boron Steel. M. Hasegaura. (*Tetsu to Hagane*, 1955, **41**, Sept., 980–981). [In Japanese].

The Extraction of Minor Phases from Austenitic Steel. J. F. Brown, W. D. Clark, and A. Parker. (*Metallurgia*, 1957, **56**, Nov., 215–223). Electrolytic solutions used by various investigators as a means of concentrating minor phases in complex alloys are discussed, and attention is given to the design of the cell. Results on a number of austenitic steels extracted with six electrolytes are given and a preferred procedure selected. Using this procedure, the authors have studied the effect of heating at 500–900° C for up to 500 h on the phases present in a series of 18/8/Ti and 18/8/Nb steels. Chromium carbide is found in all the steels, but with longer times of heating is replaced by the "sigma" phase. Relevant data on corrosion rates are also given.—G. F.

Determination of Residual Carbide in Quenched High-Carbon Alloy Steels by the Electron-Microscope. S. Kawaguchi. (*Tetsu to Hagane*, 1955, **41**, Sept., 926–927). [In Japanese].—K. E. J.

Research on the Non-Metallic Inclusions of Killed Steel. II. Y. Koike. (*Tetsu to Hagane*, 1955, **41**, Sept., 1038–1040). [In Japanese].—K. E. J.

Some Effects of Mechanical Working on the Deformation of Non-metallic Inclusions. F. B. Pickering. (*J.I.S.I.*, 1958, June, **189**, 148–159). [This issue].

Behaviour of Carbides in Ball-bearing Steels by Electrolytic Isolation. M. Ueno and H. Nakashima. (*Tetsu to Hagane*, 1957, **43**, Aug., 818–821). [In Japanese]. Carbides are more easily isolated from the annealed than the hardened steels. The annealed steels contain about 15% of carbide; nickel is more prevalent in the matrix and Mn, V and Cr (up to 98%) in the carbide. Changes in the composition of non-dissolved cementite with heating above the A_1 point are followed, and the chemical composition of the matrix is given for the hardened steels.—K. E. J.

Study on Sand Inclusions in Steel. I. The Origin of Al_2O_3 Inclusions and Effect of Mn, Si and Al on the Erosion of Refractories. N. Mizuno. (*Tetsu to Hagane*, 1955, **41**, Sept., 913–915). [In Japanese]. A linear relationship is shown between μ (=Mn−2·15 Si) and the erosion of chamotte refractories. An inverse relationship is shown between soluble Al% and erosion. Surfaces of refractories dipped in steels having various values of μ and Al% show glass, mullite and some corundum in the microstructures.—K. E. J.

On the Black Residue from Treating Carbon Steel with Warm Sulphuric Acid. IV. Samples Annealed in Hydrogen Gas at 1000° C and 1350° C. A. Kiuchi. (*Tetsu to Hagane*, 1955, **41**, Sept., 1062–1064). [In Japanese].

Thermodynamical Investigation of Non-Metallic Inclusions in Steel. II. Behaviour of Titanium, Zirconium and Vanadium Nitrides and Carbides, and their Effect on the Austenitic Grain Size of Steel. T. Mori. (*Tetsu to Hagane*, 1955, **41**, Sept., 1036–1038). [In Japanese]. Various thermodynamic relationships are expressed as equations, and the relationships between C, Ti, N and the nitrides; Ti, Al, N and the nitrides; and V, Al, Si, Fe, N and the nitrides are shown graphically for steels of given analyses.—K.E.J.

On the Metallographic Investigation of Transformer Steels. I. Hrivňák. (*Hutn. Listy*, 1957, **12**, (12), 1094–1095). [In Czech]. A micrographic study of transformer sheet produced by the German firm of W. H. Schuecker, carried out by means of the optical and electron microscopes, disclosed the presence of double and multiple boundaries of some of the ferrite grains. It is suggested that interrupted grain-growth and associated residual impurity zones may account for the phenomenon. The sheets had comparatively high watt losses. The composition was 0·03% C, 4·39% Si, 0·10% Mn, 0·1% Cu and traces of phosphorus.—P. F.

Effect of Vanadium on the Austenite Grain Size in Iron and Steel. I. K. Narita. (*Tetsu to Hagane*, 1955, **41**, Sept., 965–967). [In Japanese]. The variations of grain size with total V content and combined V content are explored.—K. E. J.

Study on the Appearance of Austenitic Grain Size. R. Kadowaki. (*Tetsu to Hagane*, 1955, **41**, Sept., 920–922). [In Japanese]. Studies were made on SH85B, SCr90, SAE 8647 and Si-Mn-Cr steels. Microstructures of temper-brittle specimens (bright and dark-field illumination) and specimens tempered at 250° C and 650° C are compared.—K. E. J.

The Effect of Silicon and Chromium on the Eutectic Austenite Transformation Occurring on Cooling Spheroidal Cast Iron. S. Drápal. (*Hutn. Listy*, 1957, **12**, (12), 1087–1094). [In Czech]. The transformation was studied in two groups of cast irons, each group comprising four melts. The silicon content in the two groups was kept constant at the respective values of 2·20 and 2·70%; the Cr contents varied from melt to melt taking the values 0·04, 0·21, 0·47 and 0·75% in each of the two groups. The remaining elements were maintained in invariant concentrations of approximately 3·15%C, 0·37%Mn, 2·75%Si, 0·03%P, 0·013%S and 0·05%Mg. The eutectoid transformation of austenite begins with the formation of ferrite. Ferrite grains appear at the austenite grain boundaries in zones close to graphite particles and at austenite-graphite interfaces. The rate of growth of ferrite grains is greatest in the vicinity of graphite particles. In the alloys low in Cr there exists a limiting cooling rate, which is the highest cooling rate at which the austenite transforms into a mixture of only ferrite and graphite. At higher cooling rates, pearlite begins to form as one of the products of the decomposition. The fraction of pearlite present after completion of the transformation increases with increasing cooling rates. The formation of ferrite can only be suppressed completely by quenching. The limiting cooling rate increases with increasing Si content. An increase in the Si content also results in a shortening of the incubation period and in an increase in the amount of ferrite present after transformation. With increasing Cr contents the limiting rate decreases at first. After a certain Cr concentration is exceeded the transformation cannot yield a mixture of only ferrite and graphite; a certain amount of pearlite is then also invariably formed. The amount of pearlite increases with the Cr content. An increase in the Cr content also increases the incubation period and, on the TTT curves, shortens the interval elapsing between the onset of ferrite and pearlite formation.—P. F.

The Effect of Some Common Alloying Elements on the Volume Change at Ac_3 of a 0·35% Carbon Steel. A. S. Kenneford. (*J.I.S.I.* 1958, June, **189**, 135–138). [This issue].

Microstructure of Iron-Chromium Alloys Annealed for Different Periods at 1200° C. A. G. Lesnik and N. P. Plotnikov. (*Problems of Metal Physics and Metallography, Metal Physics Lab. Ukrainian Acad. Sci.*, 1954, 123–127). Alloys with 24% and 35%Cr and maximum 0·04%C were examined for sigma-phase formation, with times up to 436 h. It appeared after 5 h at 760° in the 24%Cr alloy. Sigma-phase appears first at grain boundaries and later inside the grains. Microhardness was also measured, that of σ-phase varies greatly with heat-treatment, increasing with annealing time.

The Plutonium-Iron System. P. G. Mardon, H. R. Haines, J. H. Pearce and M. B. Waldron. (*J. Inst. Metals*, 1957, **86**, Dec., 166–171). A Russian diagram is confirmed and extended.

Aluminium-Rich Intermetallic-Compound Phases in the System Aluminium-Iron-Cobalt-Copper. G. V. Raynor and B. J. Ward. (*J. Inst. Metals*, 1957, **86**, Dec., 182–184).

CORROSION

Corrosion and Its Manifestations. M. G. Fontana. (*Chem. Eng. Prog.*, 1957, **53**, Nov., 525–530). A simplified picture of the corrosion process is presented.

Symposium on Corrosion Fundamentals. A. de S. Brasunas and E. E. Stansbury. (*University of Tennessee Corrosion Conference, Knoxville*, Mar. 1955. *Publ. Univ. of Tennessee Press*, 1956, pp. 255). **Corrosion and Metal Structures.** E. E. Stansbury. (1–12). A review of physical and chemical inhomogeneities in crystal structure in relation to corrosion. (17 references). **Nature of Corrosion.** A. de S. Brasunas. (13–27). A brief but comprehensive classification of terms, agents, environments, an outline of energy considerations with the equations of free energy change, electrochemical principles and the galvanic series, units and presentation of data is given. **Atmospheric Corrosion.** H. R. Copson. (28–42). Exposure testing in terms of location, humidity and similar factors is considered and the atmospheric attack on steel is reviewed with regard to composition, stainless steels and Ni alloys are similarly treated. **Coatings for Atmospheric Corrosion Protection.** J. I. Richardson. (43–49). A discussion in general terms of the action and breakdown of coatings whether metallic, conversion or applied is presented. **High Temperature Corrosion.** H. Inouye. (50–64). A general account of oxidation processes, the structure of oxide layers, and rates and rate-controlling processes, mainly of resistant non-ferrous metals, is given. **Liquid Metal Corrosion.** E. E. Hoffman (65–85). Effects of Hg, Na, Li and K-Na alloy on metal when tested under conditions simulating heat exchanger operation are reported. Mechanism of attack is discussed and corroded structures are shown. **Principles of Cathodic Protection.** M. Stern. (84–92). The electrochemistry of the method is outlined. **Corrosion Problems in Steam Power and Industrial Boiler Plants.** R. M. Lemen. (93–119). A study of conditions in the various locations of power plant is followed by a review of water treatment. **Corrosion Failures in Chemical Plants.** M. G. Fontana. (120–126). A very brief account of the kinds of attack encountered with a variety of metals with essentially practical advice on the approach to corrosion problems. **Inhibition of Metallic Corrosion in Aqueous Media.** H. C. Gatos. (127–147). Polarization processes and the action of inhibitors are reviewed. (99 references). **Passivation of Stainless Steel.** N. A. Nielsen. (148–169). Electrochemical studies are described and break-through potentials in various media are tabulated. Oxide films are considered and their structures examined by optical and diffraction methods. Film isolation is described. **The Influence of Mechanical Factors on Corrosion.** J. J. Harwood. (170–184). Electrochemical data under stress and a survey of the stress corrosion of steels and non-ferrous metals is given. The mechanism of cracking and fatigue and their prevention and fretting corrosion are discussed. **Geometric Factors in Electrical Measurements Relating to Corrosion and Its Prevention.** W. J. Schwerdtfeger and I. A. Denison. (185–205). Experiments are described with metallic couples of various shapes and the application to cathodic protection is explained. **Cathodic Protection Principles and System Design.** H. C. Van Nouhuys. (206–226). A condensed account of electrochemical factors and design considerations. **Use of Plastics and Plastic Liners for Corrosion Protection.** R. B. Seymour. (227–252). A survey of products and uses with a list of trade names.

Corrosion: Problem-Solving Methods and Materials. J. Halbig. (*Chem. Eng. Prog.*, 1957, **53**, Nov., 520–524). Notes on plant investigations of failures and design factors, inhibitors and testing methods are reviewed.

Corrosion and Tuberculation of Cast Iron. T. E. Larson and R. V. Skold. (*J. Am. Water Works Assoc.*, 1957, **49**, Oct., 1294–1302). Tests made at different rates of flow and Ca contents are reported. Ca was found to be an inhibitor independent of pH and saturation index. Tar coatings were applied leaving gaps at which tuberculation occurred.

Corrosion in High-Temperature Boilers. M. Werner. (*Werks. Korr.*, 1957, **8**, Oct., 587–596). The performance of heat-resisting steels in boilers is discussed in the light of experience gained from the most recent plant installed in Germany, which has been in operation at 600° C for about 40,000 hours. Scaling in pure steam is slight and danger only arises when the steam is appreciably polluted, the possibility of which is greatly diminished by the careful water-treatment that is common practice today. Consequently, any serious attack on the water side of the tubes is improbable. On the gas side, trouble may result from the presence of alkali sulphates in the ash. This is particularly dangerous when the operating temperature exceeds the melting point of the eutectic of mixed sulphates. Methods of avoiding this type of corrosion are indicated. For similar reasons steels containing vanadium should not be used at temperatures above 650° C.—J. C. H.

The Corrosion of 2¼%Cr–1%Mo Steel by Liquid Bismuth. G. W. Horsley and J. T. Maskrey. (*J.I.S.I.*, 1958, June, **189**, 139–148). [This issue].

Corrosion and Wear Handbook for Water-Cooled Reactors. D. J. DePaul (Editor), for U.S. Atomic Energy Commission. (1957, pp. 293). **Introduction.** (3–10). General information is given on steels and on high-purity water. **Fundamental Aspects of Iron Corrosion.** D. L. Douglas. (11–20). The mechanism of corrosion and of early and later stages of film formation and effects of occluded H_2 are discussed, and also the effects of the pH, dissolved salts, O_2, H_2, and effects of rate of flow of the water, and of alloying elements in the iron are considered. The thermodynamics of the system are particularly dealt with. **Fundamental Aspects of Friction and Wear.** J. W. Flaherty and S. Petach (Editors). (21–30). Friction theory and the process of wear are reviewed. **Water Technology.** D. M. Wroughton. (31–36). With special reference to corrosion. **Description of Testing Procedures.** R. V. Blaser (Editor) and 16 contributors. (39–74). Test systems, water control and analysis, general corrosion testing, special tests (galvanic, crevice, stress, corrosion fatigue, heat transfer), and wear and friction testing methods are surveyed. **The Approach to Corrosion Problems.** D. J. DePaul and W. F. Brindley. Further discussion of test procedures is given. **Tabulation of Basic Data.** D. J. DePaul and J. W. Flaherty (Editors), and 23 contributors. (95–133). Static and dynamic test data and wear test data are shown for 18 stainless steels and other alloys. **The Relative Importance of Different Variables.** D. J. DePaul (Editor), and three contributors. (135–143). Composition, time, rate of flow, O_2, H_2, NH_3 and inert gases, pH, electrical resistivity, stress, heat-treatment, irradiation and surface finishes are briefly reviewed. **Crevice Corrosion.** D. J. DePaul and two contributors. (147–185). Mechanism, control measures, and influence on bearings, springs, rivets and bellows are surveyed, with tabulated results of contact tests for 14 and 44 days on numerous materials. **Stress Corrosion.** W. L. Williams and J. F. Eckel (Editors), and 20 contributors. (187–223). An illustrated review is given of factors in the process and control measures, mainly for stainless steels. Laboratory tests are described and experience with boilers and heat exchangers is referred to. (53 references). **Intergranular Corrosion.** D. J. DePaul (Editor) and seven contributors. (225–228). **Corrosion Products in Recirculating Systems.** B. G. Schultz (Editor) and four contributors. (229–238). The properties of corrosion products, their deposition and removal are discussed. **Application Considerations of Wear.** J. W. Flaherty and S. Petach (Editors) and three contributors. (239–261). Choice of materials is included. **Manufacturing Procedures Affecting Corrosion and Wear.** D. J. DePaul (Editor) and two contributors. (263–272). Machining, grinding, polishing, grit blasting, lubrication, acid cleaning, degreasing, drying and preparation for transportation are reviewed.

Electron Optical Studies of Oxidation Processes Occurring in High Vacuum. E. A. Gulbransen and K. F. Andrew. (*Committee on Vacuum Techniques, Symposium on Vacuum Technology*, 1956, *Chicago*, 1957, 190–201). Studies of the reaction of pure iron with residual gases in a vacuum system and at low O_2 pressures at 650° and 850° C. Oxide nucleus formation is observed and further effects of carbon, if present, occur. Under low pressures at 850° C bulk structure of the metal after heat treatment can be studied, and oxidation occurs at defects and other nucleation centres. For pure Fe, vacuum heat-treatment at 850° gives a surface showing random distribution of defects. In H_2 the arrangement is highly ordered, as disclosed by O_2 exposure.

Phase Diagrams for Oxidation of Metals. E. H. Bucknall (*Met. Prog.*, 1957, **72**, Sept., 110, 112, 114). The author suggests that the oxidation of binary alloys be represented by means of triangular phase diagrams. As an example, using the results of Sachs, he presents an isothermal section of the ternary system Fe-Ni-O, with oxygen partial pressures shown as isobaric contours. An explanation of the different fields is given.—G. F.

The Influence of Trace Elements on the Resistance of Heat-resisting Alloys to Scaling. H. Pfeiffer. (*Werks. Korr.*, 1957, **8**, Oct., 574–579). Oxidation tests on laboratory casts of heat-resisting alloys have confirmed that trace elements can have a determining influence on their resistance to scaling. For example, the life of an Fe-Al-Cr alloy wire at 1200° C was multiplied ten times by the addition of 0·005% Ca to the metal. Tests with radioactive alloying elements indicate that the trace elements probably act by accumulating at the metal/oxide interface, where they offer a barrier to the outward diffusion of the metal through the oxide formed. Pure Fe-Al-Cr alloys yield a mixture of oxides of the component metals but on less pure commercial products a film of pure alumina results. The author doubts, however, whether this is due to the presence of trace elements and considers that their importance lies in improving the adhesion of the oxide film.—J. C. H.

Influence of Bicarbonate Ion on Inhibition of Corrosion by Sodium Silicate in a Zinc-Iron System. H. L. Shuldener and L. Lehrman. (*J. Am. Water Works Assoc.*, 1957, **49**, Nov., 1432–1440). An accelerated test was used and it is confirmed that silica is taken up by corrosion products forming a protective deposit and that $Zn(OH)_2$ is more effective than $Fe(OH)_2$ in removing silica from water containing sodium silicate. Temperature, pH and water composition effects are noted and an explanation is offered. (21 references).

Sodium Benzoate as a Corrosion Inhibitor in Water Emulsions. H. J. Freier and W. Geilenkirchen. (*Werks. Korr.*, 1957, **8**, Nov., 673–677). Sodium benzoate, either alone or mixed with sodium nitrite, has been found to be a useful inhibitor of the corrosion of steel containers, black or tinned, for water-emulsion paints. The amount of inhibitor required depends mainly on the acidity of the emulsion; usually an addition of 2% of inhibitor is effective.—J. C. H.

ANALYSIS

Temperature Measurement of Iron and Steel Samples in a Graphite Crucible for Gas Analysis. N. Yoneda. (*Tetsu to Hagane*, 1957, **43**, June, 657–662). [In Japanese]. Data obtained in an investigation of accurate temperature measurements for analytical work show that the emissivity should be calculated in relation to the size of crucible used.—K. E. J.

Study of Gas Analysis by the Vacuum Fusion Method Applied to Routine Work. S. Shinoda. (*Tetsu to Hagane*, 1955, **41**, Sept., 1066–1068). [In Japanese].—K. E. J.

Effect of Amines on the Determination of Nitrogen in Pig-iron. M. Ihida. (*Tetsu to Hagane*, 1955, **41**, Sept., 1059–1062). [In Japanese]. Data are given for various procedures, comparing mono-, di- and tri-methylamines. Comparisons are made between results from titration and photometric methods of the acids used under various conditions.—K. E. J.

Quantitative Inorganic Chromatography. III. Separation and Determination of Ferrous and Ferric Iron. F. H. Pollard, J. F. W. McOmie, A. J. Banister and G. Nickless. (*Analyst*, 1957, **82**, Dec., 780–800). (60 references).

Oxine Complex of Molybdenum. D. V. Ramana Rao. (*Anal. Chim. Acta.*, 1957, **17**, Dec., 538–540). The pH range for formation is closely defined.

Interferences of Three Elements in Flame Photometry: Cr-Co-Mn System. F. Burriel-Marti, J. Ramirez-Muñoz and M. C. Asuncion-Omarrementeria. (*Anal. Chim. Acta.*, 1957, **17**, Dec., 545–558). Correction methods are reported.

On the Increase in Accuracy for Spectrographic Analysis of Samples of Molten Steel. T. Suzuki (*Tetsu to Hagane*, 1955, **41**, Sept., 1064–1066). [In Japanese]. Correlations are established between Si and Mn contents in carbon steel as determined by chemical and spectrographic methods, and values for Si, Mn, Ni, Cr and Cu are compared for ten samples by the two methods.—K. E. J.

INDUSTRIAL USES AND APPLICATIONS

Steel Can Be Used to Produce Lighter Aircraft. B. Mitchell. (*S.A.E.J.*, 1957, **65**, Dec., 56–58). The use of thin sheets of 17-7PH steel with proper design is described, and comparisons with Ti, Al and Mg alloys are given.

"Mach 4" Stainless for 1000° Service Beats Aircraft Thermal Barrier. (*Western Metalw.*, 1957, **15**, Oct., 62). Armo Steel Corp. PH 15-7Mo steel is described. It is precipitation-hardening and will resist flight conditions at 2,700 m.p.h.

HISTORICAL

A History Lesson on Nineteenth Century Metallurgical Industry. R. Chadwick. (*J. B'ham. Met. Soc.*, 1957, **37**, Dec., 566–595). A review of the relative decline of the British wrought iron and steel industries during the second half of the century, with accounts of tinplate and wire production and the armour plate and gun forging and pressing industries, and the reasons for the decline. Copper, Zn and jewellery are also reviewed.

The Travel Diaries of Swedish Engineers of the Eighteenth Century as Sources of Technological History. M. W. Flinn. (*Trans. Newcomen Soc.*, 1958, preprint, pp. 17). Visits to British Iron and Steel works are recorded.

Age of Iron Production on the Banks of the Lower Sieg. J. W. Gilles. (*Stahl Eisen*, 1957, **77**, Dec. 26, 1883–1884). An historical assay of early iron production in the Sieg district of Germany.—T. G.

Blast Furnace U.S.A.: III. From Falling Creek to Zug Island. M. O. Holowaty and C. M. Squarcy. (*J. Met.*, 1957, **9**, Oct., Section I, 1367–1372). Continuing their history of blast furnace development in the U.S.A., the authors discuss the transition from bituminous coal furnaces to coke furnaces and then describe the gradual increase in pig-iron capacity in the 20th century.—G. F.

Company Histories. 3. Colvilles. A. Rhodes. (*Steel Rev.*, 1958, Jan., 6–15).

ECONOMICS AND STATISTICS

The Place of the Iron and Steel Industry in the Australian Economy. I. M. McLennan. (*Proc. Australasian I.M.M.*, 1957, Sept., 1–15). An address. The present industry is reviewed.

Steel 1957-58. (*Steel Rev.*, 1958, Jan., 1–5). A review of 1957 and a forecast for 1958, mostly statistical.

MISCELLANEOUS

Industry's Water Problems and Their Solution. H. I. Riegel. (*Iron Steel Eng.*, 1957, **34**, Nov., 73–78). The limited water supply in California and stringent pollution requirements necessitate extensive water handling and treatment at the Fontana plant of Kaiser Steel Corporation, where water consumption is kept down to 1400–1600 gal/t of steel. The author gives details of the system used.—G. F.

Pilot Runs Up Your Odds. (*Steel*, 1957, **141**, Dec. 16, 102–105). Advice on pilot production runs is given. Various experiences are referred to in machining and finishing processes.

Design of Pyrometallurgical Pilot Plants. R. C. Buehl. (*J. Met.*, 1957, **9**, Oct., Section I, 1359–1362). The author discusses some of the problems involved in the design of pilot plants to study entire pyrometallurgical processes. He considers the instances of electric arc furnaces, blast furnaces, O.H. furnaces, and converters, and discusses the relation of the pilot plant to the industrial plant. The importance of the heat loss problem is emphasized.—G. F.

Application of Mathematical Statistics in the Iron Industry. K. Orths. (*Stahl u. Eisen*, 1958, **78**, Jan. 9, 14–21). The author describes methods and results obtained of quality-control statistics in integrated iron and steel works.—T. G.

Industrial Statistics Help Solve Steel Plant Managerial Problems. P. E. Green and I. L. Haines. (*Iron Steel Eng.*, 1957, **34**, Oct., 118–123). The authors describe operational research methods used in steelworks to help solve managerial problems such as inventory control, production scheduling, preventive maintenance, capital expenditure analysis and long range planning.—M. D. J. D.

Waste Heat Recovery. (*Overseas Eng.*, 1958, **31**, Jan., 198–203). The use of waste heat boilers in steel and other works is described, also boilers operating on blast furnace gas.

BOOK NOTICES

CALVO RODÉS, RAFAEL. "*Metales y Aleaciones.*" Tomo II. Su Constitucion, Estructura, Propiedades y Tratamientos. 9¾ × 6¾ in., pp. xx + 720. Illustrated. Madrid, 1957: Instituto Nacional de Tecnica Aeronautica "Esteban Terradas."

This is the second volume of a work, the first of which was published in 1948 and reviewed in the J.I.S.I. for April, 1950.

The first two-thirds of the book, approximately, deals with properties and has chapters on physical properties, oxidation, corrosion, mechanical properties, processes of deformation and fracture in monocrystals and in polycrystalline metal, influence of time and temperature on deformation and fracture, creep, and mechanical testing.

The remainder of the book deals with treatments and covers reactions in the solid state, phase transformations, variations in structure, thermal and mechanical treatments, and the behaviour of metals in hot and cold working.

The book deals, in a completely systematic manner, with the effect of external agents on metal and with the interrelated factors associated with the nature of the metal itself. It gives a reasonably full treatment of each of the subjects covered, and has 457 illustrations.

This second volume has an index which also covers the first volume.—R. SEWELL.

CONSIDINE, DOUGLAS M. (editor). "*Process Instruments and Controls Handbook.*" Prepared by a Staff of Specialists. La. 8vo, pp. xxiii + 1600; (14 sections, not continuously paginated). Illustrated. New York, Toronto, London, 1957: McGraw Hill Book Company, Inc. (Price $19.50).

The editor of this handbook should be congratulated on the scope of the text. The general presentation is very good, apart from one or two features which give rise to criticism, and the diagrams have obviously been prepared with some care.

The early chapters deal with basic measuring elements in the fields of temperature, pressure, flow, etc., and show how they are incorporated in complete instruments, with examples from current American practice, well illustrated by line drawings. It is felt, however, that some well-chosen photographs might profitably have been included. Among some significant omissions are measurements on dust, smoke and fume densities, and on material thickness. These chapters are followed by sections dealing with display instruments, telemetering and actuating elements such as control valves.

Section II gives an excellent introduction to the theory of servo-mechanisms and process control, and to such concepts as the Laplace Transform and transfer functions. This section also serves to emphasize a major defect in editorial style, since it repeats, in part, information given earlier in the section on pneumatic controllers. One is aware in several places that information of general application is tucked away under a specialized heading. In this particular case, discussion of servo theory could well precede the accounts given of the behaviour of pneumatic and electrical controllers.

The book concludes with a section of reference data, a glossary of technical terms and a note on instrumentation flow-plan symbols prepared by the Instrument Society of America. It is interesting to compare these symbols with B.S.1646. References in the text are tabulated at the ends of chapters, and the pages, unlike many American publications, are not cluttered with a mass of footnotes.

B. O. SMITH.

"*Directory of National Organisations in Europe and the U.S.A. and International Organisations Concerned with Iron and Steel.*" 8vo, pp. 106. London, [1957]: Quin Press Ltd. (Price 20*s.* 0*d.*).

This is a fairly useful if slender directory which was prepared by the Secretariat of the U.N. Economic Commission for Europe. In view of this it is surprisingly expensive for its size. It covers some, but by no means all, international and national organizations concerned with iron and steel in Europe and the U.S.A. and gives the scope, structure and publications of each organization mentioned. Information was obtained from governments and the organizations listed and perhaps, because of this the entries vary a great deal in comprehensiveness and detail. Rumania appears as a (duplicated) addendum and the Irish Republic, the Saar (politically now part of Western Germany), and Portugal (a newcomer to steel production) not at all.—M. L. P.

FAIRES, R. A., and PARKS, B. H. "*Radioisotope Laboratory Techniques.*" Newnes Practical Science Books. 8¾ × 5½ in., pp. xii + 244. Illustrated. London, 1958: George Newnes Ltd. (Price 25*s.*).

During the last decade, many artificially produced radioactive isotopes have become available, but few text books have been published on the application of these materials to research or other problems. The present book is one of the Newnes Practical Science Series, whose aim is to provide up-to-date information on modern experimental techniques. In fulfilling this function, it caters for the needs of the non-specialist in radioisotope methods, or for the needs of the scientist or technologist interested in the use of these methods in specific problems.

The book is well written and illustrated, and makes a very readable introduction to radioisotope laboratory techniques. It is inevitable in a book of this size that certain of the subject matter is treated rather sketchily, but the numerous suggestions for further reading provide a useful source of additional information.

The book may be divided broadly into

four sections. In the early chapters, the elements of nuclear physics, production of radioisotopes and health physics aspects are described. These are followed by chapters on the design of various types of radioisotope laboratory, control of hazards from radiation or toxicity, and decontamination and disposal of waste materials. The section dealing with detection and measurement is treated from a practical aspect, and indicates the points to be considered in choosing equipment. Finally, there is a review of a number of practical applications of radioisotopes, and a description of methods of assessing the feasibility of using isotopes in a particular problem.—A. G. KNAPTON.

GOLDMAN, J. E. (Editor). "*The Science of Engineering Materials.*" 8vo, pp. xx + 528. Illustrated. New York, 1957: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd. (Price $12.00, 96*s.*).

This book constitutes the proceedings of the Carnegie Conference of leaders of engineering education in the United States on the Impact of Solid-State Science on Engineering Education. The conference was held in June 1954 and unanimously recommended that engineering curricula should incorporate formal courses in the Theory of Solid-State.

Science and engineering have been interwoven closely throughout the history of modern technology and it is now apparent that solid-state science is becoming an essential part of the discipline of engineering. Engineers have reached a mode of thinking which may be called "molecular engineering" instead of taking prefabricated materials and trying to devise engineering applications consistent with their macroscopic properties.

The term "Engineering Materials" is used in this book in a broad sense and chapters are included on materials such as cements, polymers, glasses, semi-conductors, and dielectrics. Surface phenomena are dealt with in one chapter which covers a wide field—friction and adhesion, adsorption and catalysis, corrosion and electron emission. Two chapters are devoted to magnetic materials, the first is on the theoretical basis of magnetic phenomena and the second on the physics of magnetic materials.

The chapters on metals and alloys naturally constitute the major part of the book. The papers progress logically from the fundamental studies of the metallic state and the electron theory of alloy formation to the dislocation theory of mechanical properties. This part of the book is terminated with a chapter on phase transformations and their influence on mechanical properties.

Much of the material in this book has been published elsewhere and in parts it may be considered out of date, especially the chapter on the experimental evidence for the behaviour of dislocations. However, this criticism must not be taken too seriously in a rapidly advancing branch of technology.

The collection into one volume with bibliographies and references following each chapter gives a book useful to all workers in the field of applied solid-state science. The binding, paper and printing are excellent. This book should find its rightful place on the library shelves of research organizations, universities, and colleges of technology.—A. H. MELEKA.

KONOPICKY, KAMILLO. "*Feuerfeste Baustoffe. Herstellung und Verwendung.*" Stahleisen-Bücher Band 14. La. 8vo, pp. xiv + 553. Illustrated. Düsseldorf, 1957: Verlag Stahleisen m.b.h. (Price DM. 57.50).

The phrase naturally occurring to the reviewer on studying this book of 553 excellently-printed pages, 225 well-produced figures, and 1173 references is "Teutonic thoroughness."

The first 34 pages on the constitution of refractories are noteworthy for a section on phase equilibrium diagrams, in which the author attempts to teach the subject in terms of hypothetical systems. Then follow 55 pages on properties and testing, containing sections on service behaviour which rightly consider melt viscosity important, but confine the wider term "resistance to temperature changes" to orthodox spalling resistance. The 43 pages given to methods of preparation seem to cover this subject adequately, Fig. 50 summarizing the effects of grain size distribution on properties in a way which reveals the necessity for compromise.

Although 130 pages are allotted to describing the different types of refractories, there is almost no subdivision of subject matter within the various sections. The section on silica contains no reference to the CaO–Al_2O_3–TiO_2–SiO_2 system, a subject of admittedly little importance in Germany, but surely worthy of note. In the section on basic refractories there is no reference to phase relationships in iron-oxide-containing spinel systems, except in terms of Dr. Konopicky's original discovery of the oxidation of raw chrome ores on heating.

After a short section on combustion, heat transfer and temperature measurement, the rest of the book admirably details the use of refractories in power-producing (including nuclear-energy) plant; in the glass, enamel, cement and chemical industries; in all aspects of the iron and steel industry; and in the non-ferrous metal industry.

In spite of some lack of discrimination in choosing many of the numerous references, and in selecting some of the diagrams, the book can be thoroughly recommended. Only one error has been noted; that, curiously enough, concerns the reviewer's initials.—W. F. FORD.

LECK, J. H. "*Pressure Measurement in Vacuum Systems.*" Physics in Industry Series. 8vo, pp. 144. Illustrated. London, 1957: The Institute of Physics; Chapman & Hall Ltd. (Price 30*s.*).

The last extensive review of gauges for pressure measurement in vacuum systems was published in 1949 as a chapter of rather more than 100 pages in Dushman's work on Vacuum Technique. Hence, an up-to-date review of the situation to-day is timely. For example, it is noted that of the 192 references given in the present book, more than 50 relate to work carried out since 1949. The first four chapters deal with mechanical manometers, thermal conductivity gauges, ionization gauges, and the Knudsen radiometer gauges. A brief chapter 5 refers to work on surface reaction techniques to estimate residual pressures of less than 10^{-10} mm of mercury such as are now obtained by modern pumps using ion pumping and the gettering action of continuously evaporated metals. The final chapter deals briefly with gauge calibration. A number of gauges given in Dushman's work are now eliminated as being only of historic interest. It is a pity, however, that no reference has been retained to the use of a discharge tube of the type described by G. Burrows (*J. Sci. Instrum.* **20**, 21, 1943). This is still much valued by vacuum technicians to estimate pressures down to 1 micron and to give some information about the kind of gas or vapour present.

To the reviewer, it appears that the book is primarily directed to those workers who are interested in gauge design and who wish to be informed of the present position. These may advance with the certainty that they are not repeating what has been adequately done before nor searching for a result now shown to be impossible of attainment.

For other workers, a chart, table or diagram summarizing very briefly the useful pressure ranges of all the different types of gauges, with the relevant advantages and disadvantages (cross-referenced to the text), would, it is felt, have stimulated a wider field of interest, particularly if, at the same time, some instruction had been given on the position of the gauge in the vacuum circuit, size and length of piping to use, and expected equilibrium times in various examples good and bad. Nevertheless, the book will clearly be of value to very many occupied with pressure measurement in vacuum systems. The production is of the quality now expected of the Physics in Industry series.—G. P. BARNARD.

LUCAS, G., and POLLOCK, J. F. "*Gas Turbine Materials. A Survey of High Temperature Materials and their Application to the Gas Turbine.*" 8vo, pp. xi + 163. Illustrated. London, 1957: Temple Press Ltd. (Price 25*s.*).

The authors state that the book is intended to be a survey and not a detailed treatment, and should be of value to engineers, metallurgists, and students. It begins with an outline of the development of high temperature materials, and proceeds to a description of the operating conditions in a gas turbine in terms of idealized thermodynamic cycles. A chapter on metals under stress and temperature deals effectively with the subject of creep, although there is no mention of methods of predicting long term creep data from relatively short time tests; this chapter has a good section on oxidation and high temperature corrosion, but fluctuating stresses are inadequately treated.

The description of the materials used for the major engine components lacks detail. In a book of this kind, comprehensive mechanical property data would be inappropriate, but data for one material representative of each type would have been valuable. The section on heat exchangers (p. 101) needs revision, as the emphasis placed on the temperature drop through the tube wall and the importance of material thermal conductivity is quite misleading. There is a chapter on relatively new high temperature materials based on refractory metals and compounds which covers the subject satisfactorily, although these materials have not yet begun to establish themselves in gas turbine engineering. The chapter on manufacturing methods is not as closely connected with the production of gas turbine alloys and components as it could be, and the great importance of extrusion in the hot working of the strongest Nimonic alloys appears to have been overlooked.

The book does not adequately reflect the paramount influence of the aircraft gas turbine on current progress, compared with the industrial turbine. The vitally important nickel base alloys used for turbine blading deserve more extensive treatment, which might well include recent contributions to our understanding of the physical metallurgy of these alloys; by comparison, the space devoted to the discussion of fuels is excessive. There are some excellent photographs of gas turbine engines which do not seem to be directly related to the text, but there is a noticeable absence of illustrations of metallurgical features of the materials discussed, e.g. components found to be defective in service.

The book contains a considerable number of minor errors and misleading statements, and has too many shortcomings to be recommended with confidence.—T. A. TAYLOR.

SJÖSTRAND, F. S., and J. RHODIN. "*Electron Microscopy: Proceedings of the Stockholm Conference, Sept.* 1956." 10 × 7 in., pp. xi + 355. Illustrated. Stockholm: 1957. Almqvist & Wiksell. (Price Sw. Kr. 80).

Although the number of papers of direct concern to metallurgists would appear to be small, the very complete accounts of methods and technique throughout the volume make this, and the previous volume (see *J.I.S.I.*, 1957, **186**, July, 384) quite indispensible for the user of the electron microscope in any field of research. Indeed, the first IV sections, 103 pp., are entirely concerned with instrumentation, electron optics, electron-specimen interaction, and high-resolution electron microscopy and electron diffraction, and would be of value to any worker interested in sub-microscopic detail. Metallography is directly represented by the following papers: Direct observation of dislocations and their movement in metal foils, by P. B. Hirsch *et al.* of Cambridge; Dislocations in stainless steel,

by W. Bollmann, of the Battelle Institute, Geneva; Migrations of grain boundaries studied with the Electronic Emission Microscope, by R. Arnal and M. Sorel, of Paris; Pearlite and Bainite structure in three steels with 0·18%, 0·50%, and 0·86% C, by S. Modin of Stockholm; Use of a new method of electrolytic polishing, by R. Zetzsche *et al.*, of Jena; Electron-optical investigations of metallurgical dusts, especially their preparation and physical differentiation by A. M. D'Ans and L. v. Bogdandy, of the Max-Planck Co., Berlin-Dahlem; and the electron microscope in the study of wear, by D. and H. M. Scott, of the Mechanical Engineering Research Lab., Glasgow, as well as non-ferrous papers. Abstracts of the above will appear in our abstract section. Papers are published in English (92), French (7), and German (40). The standard of the communications is of the highest quality and the illustrations are naturally outstanding, as would have been expected from previous issues.—J. G. C.

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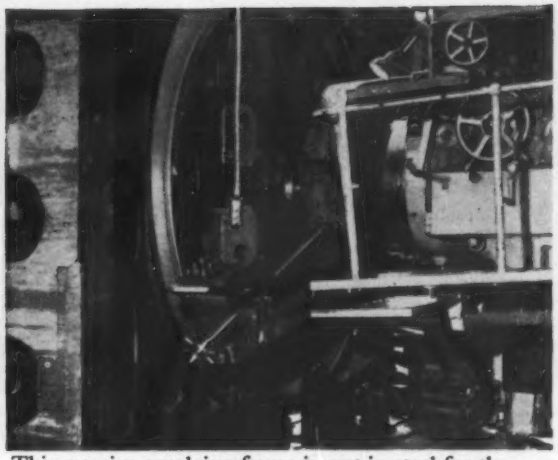
cast and machined for an important part



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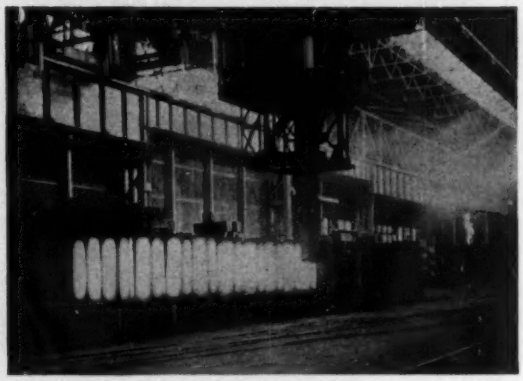

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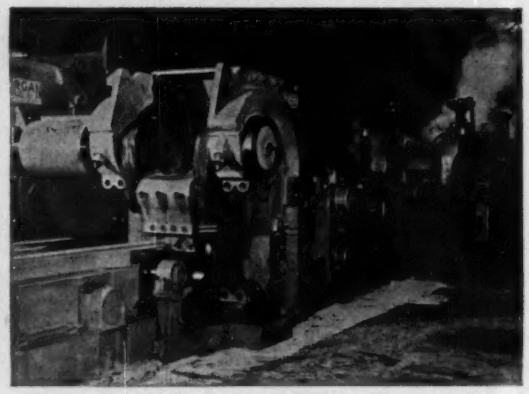

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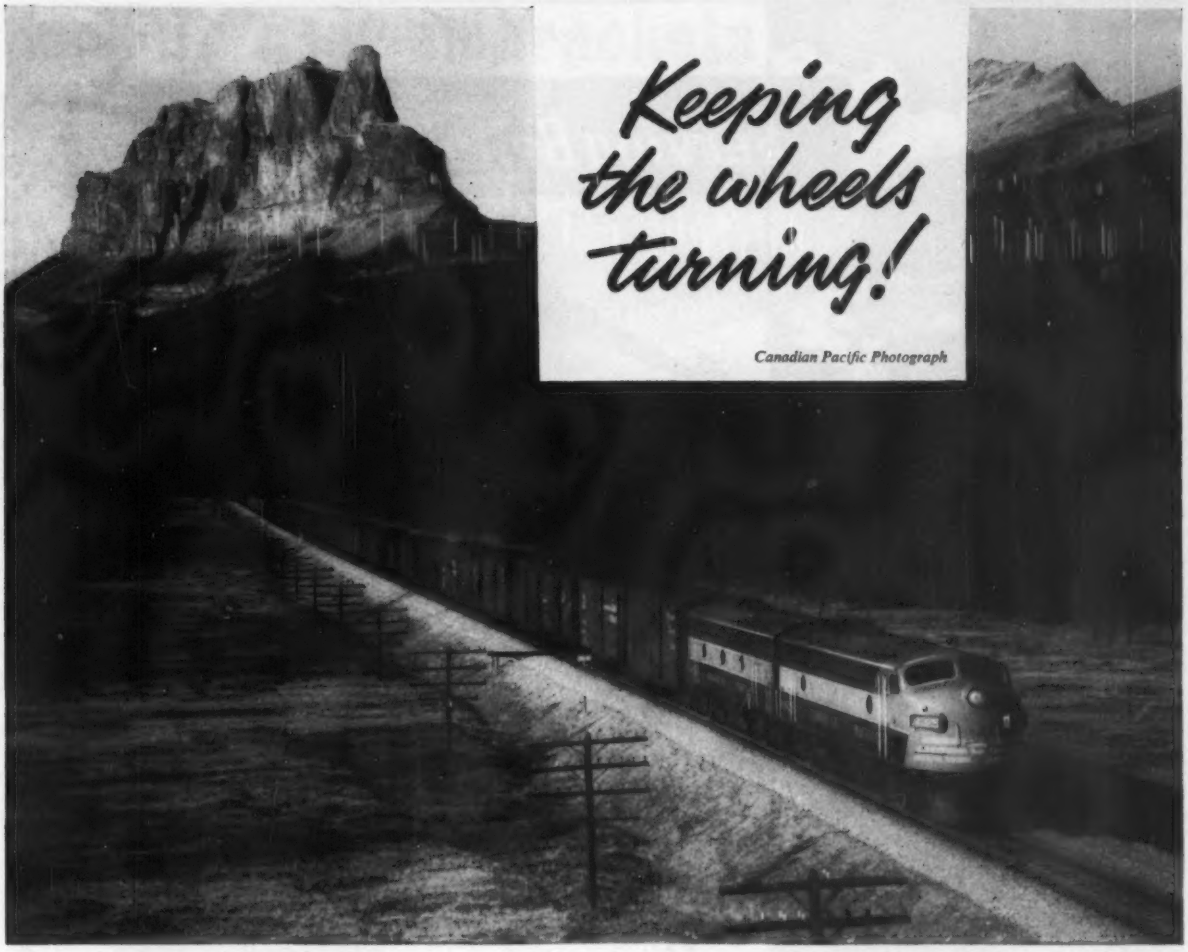

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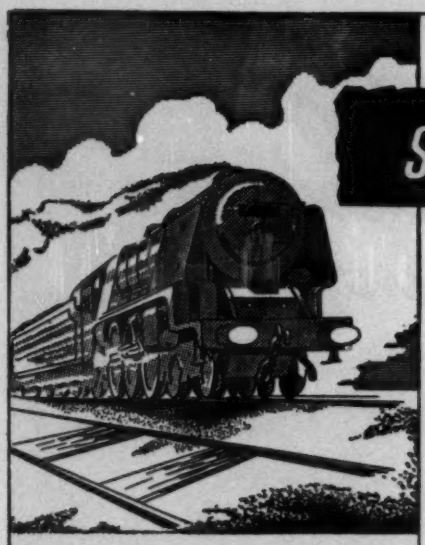

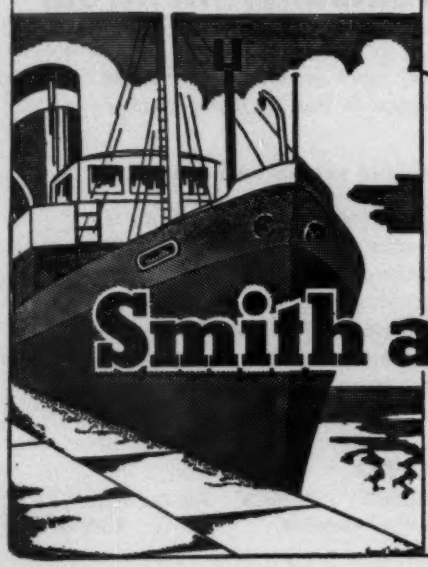

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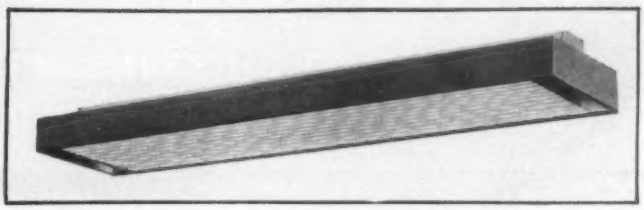

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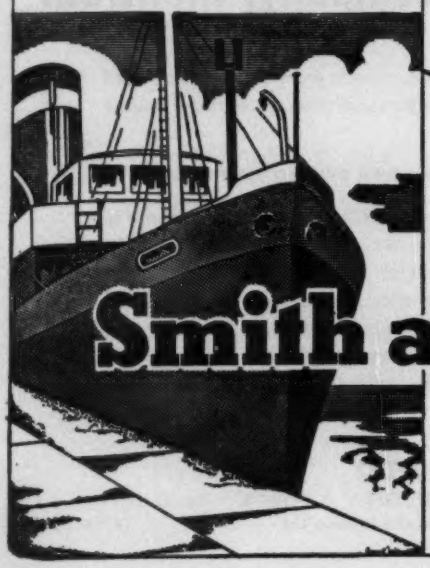

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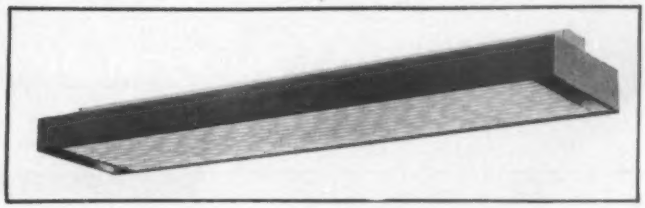

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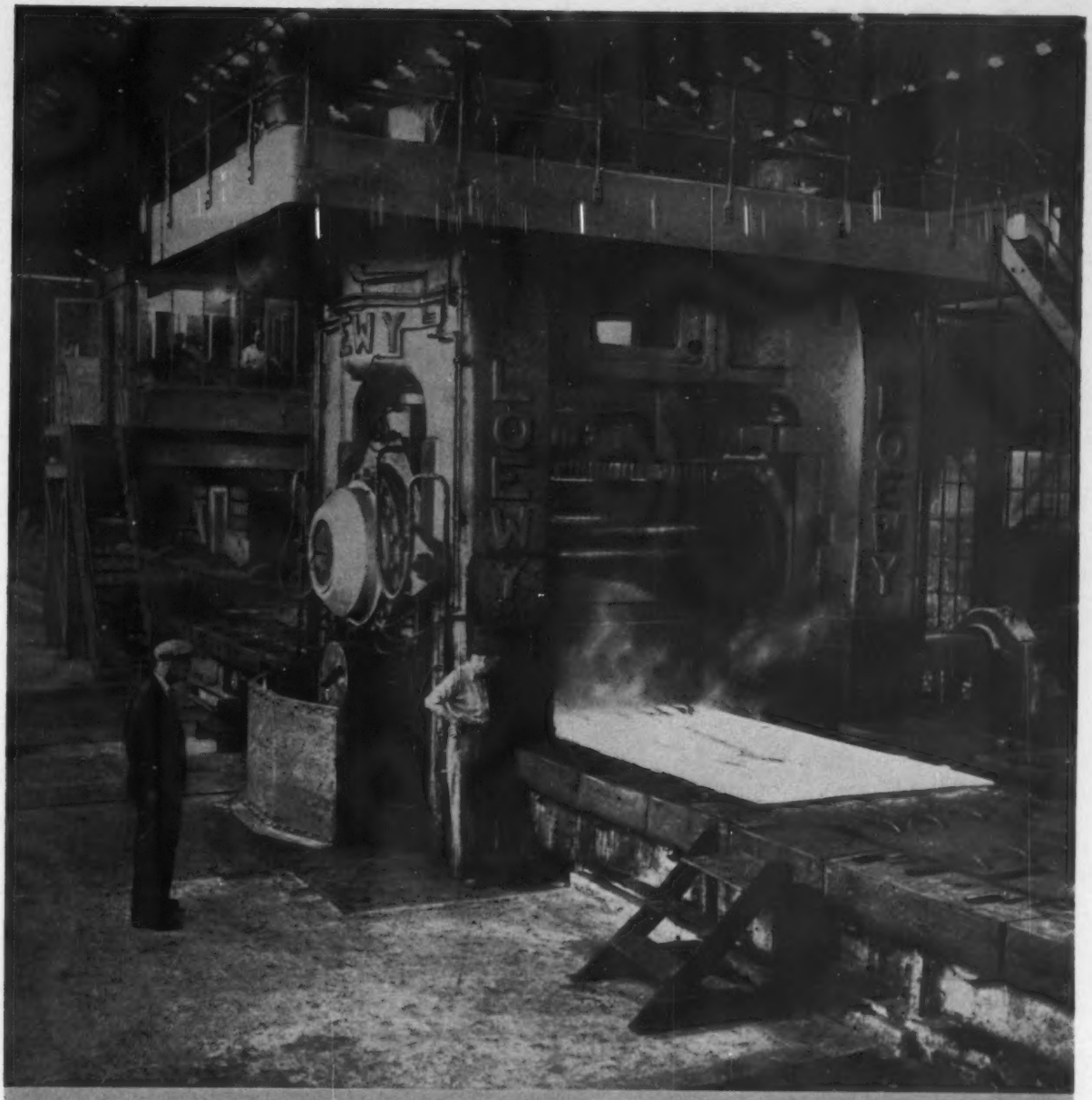

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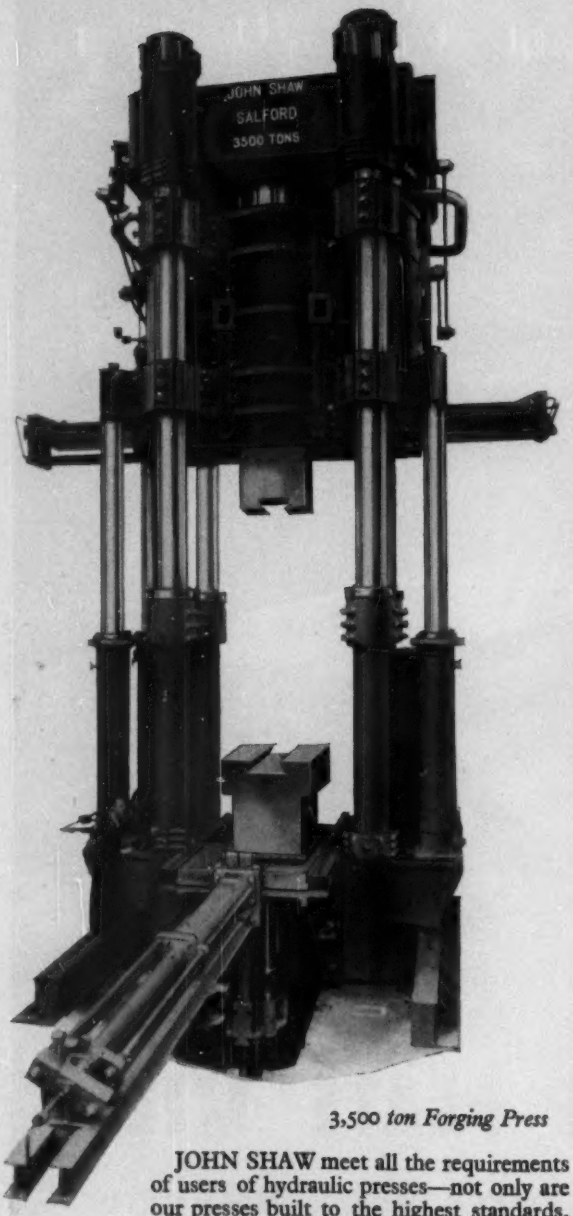

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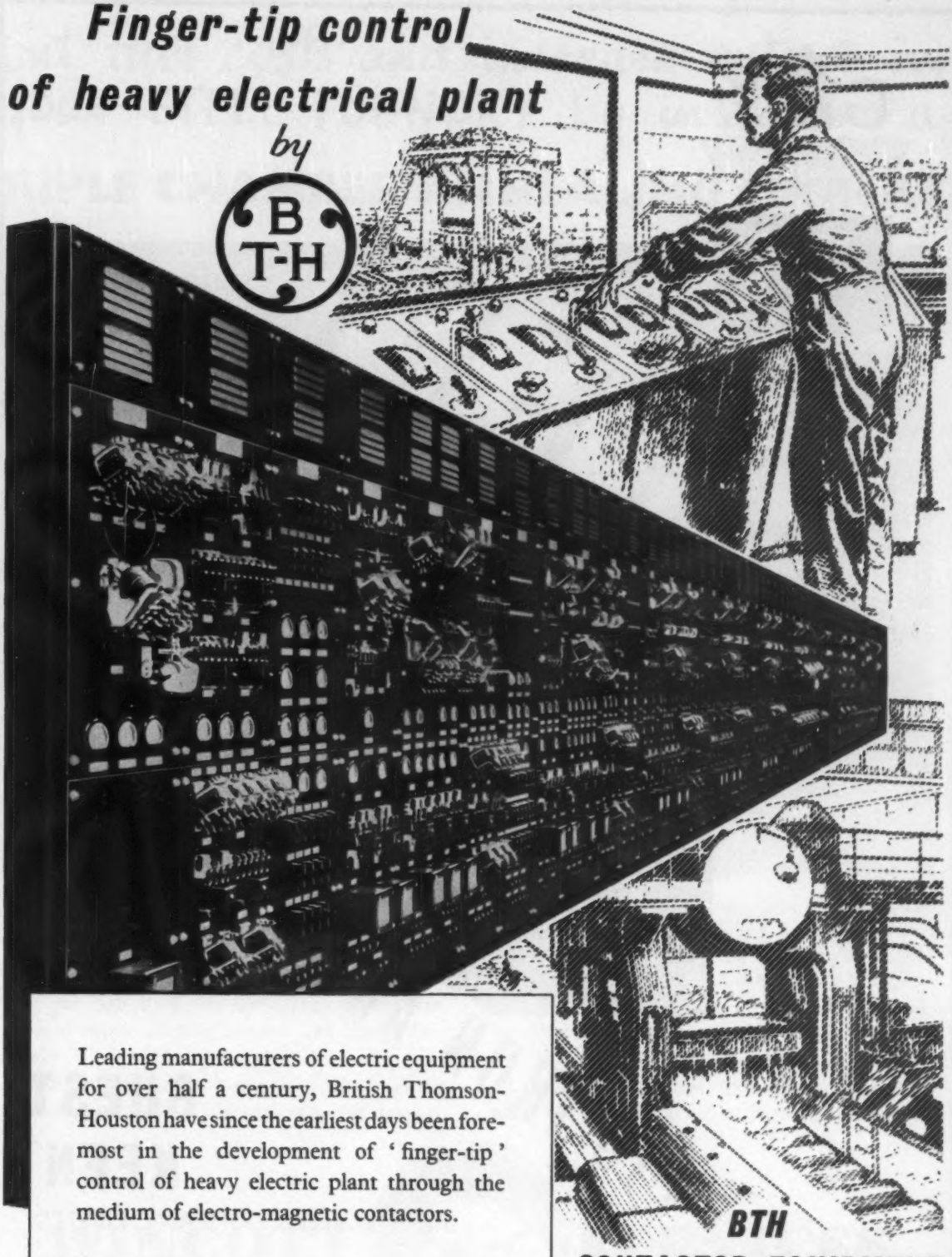

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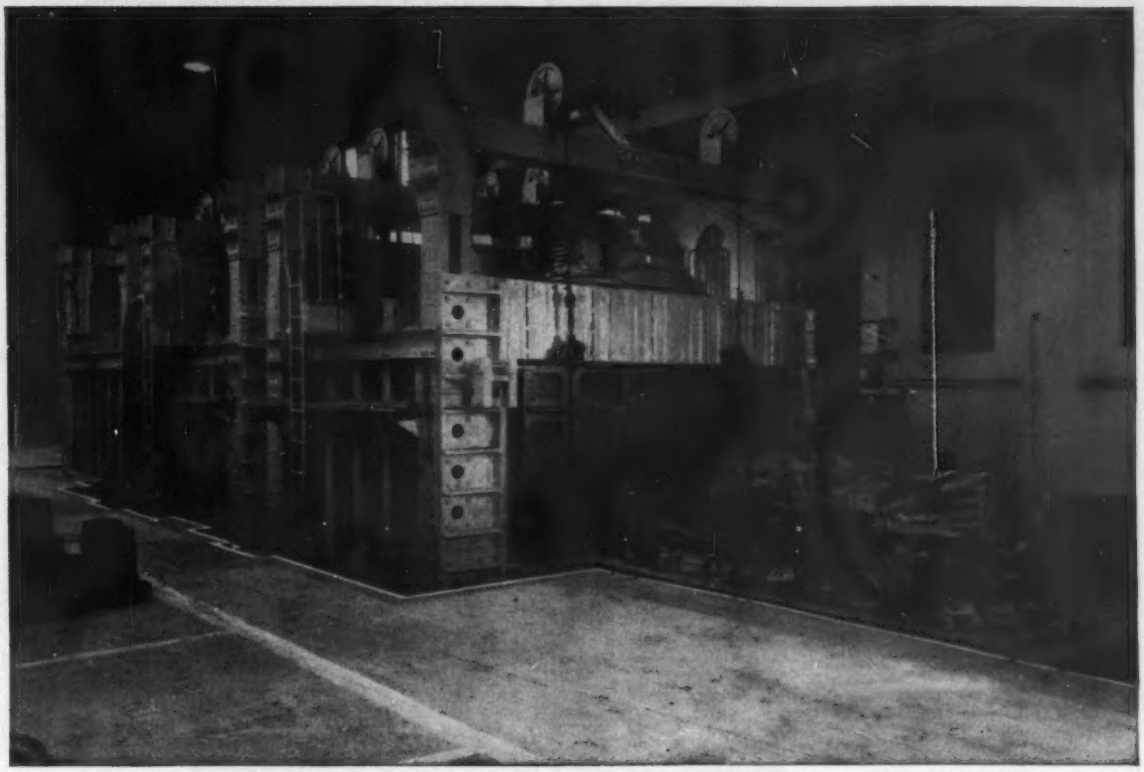

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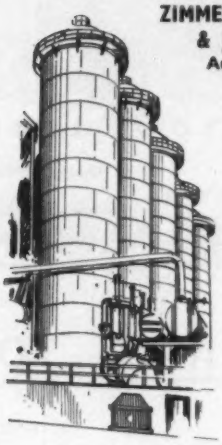

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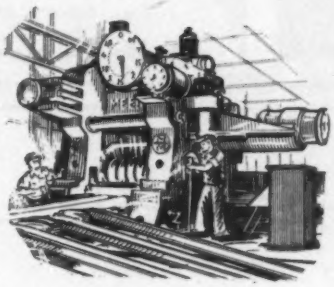

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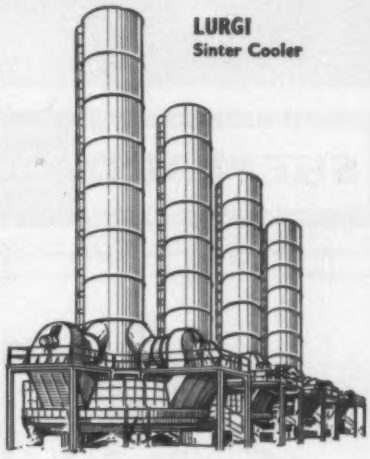

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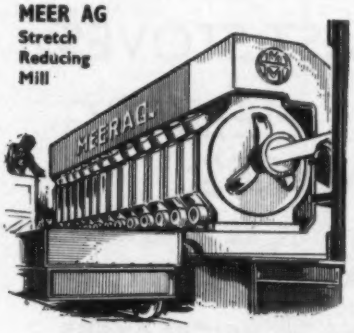

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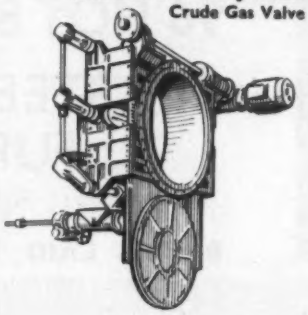

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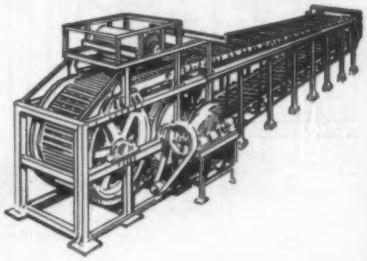

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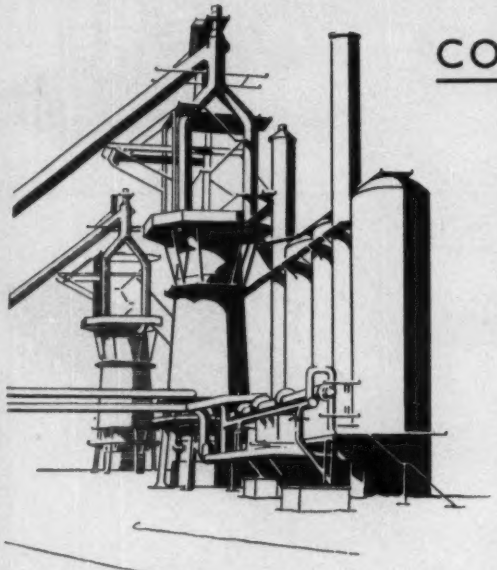

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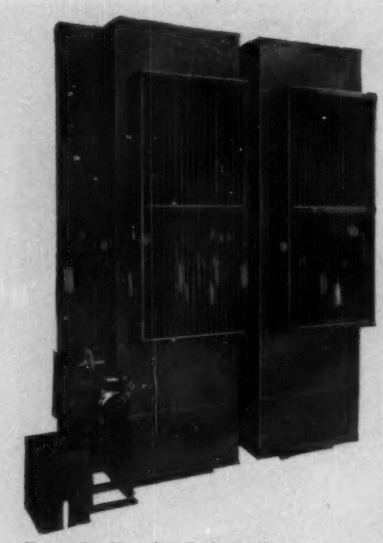

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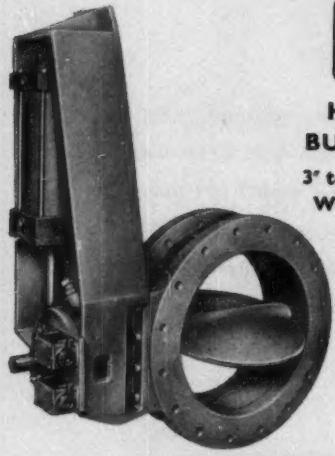

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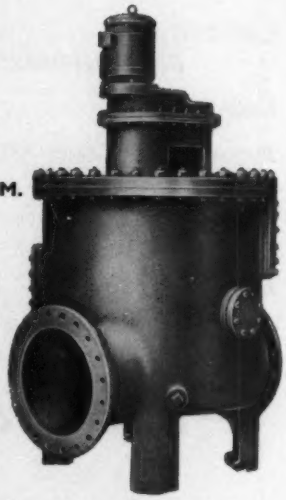

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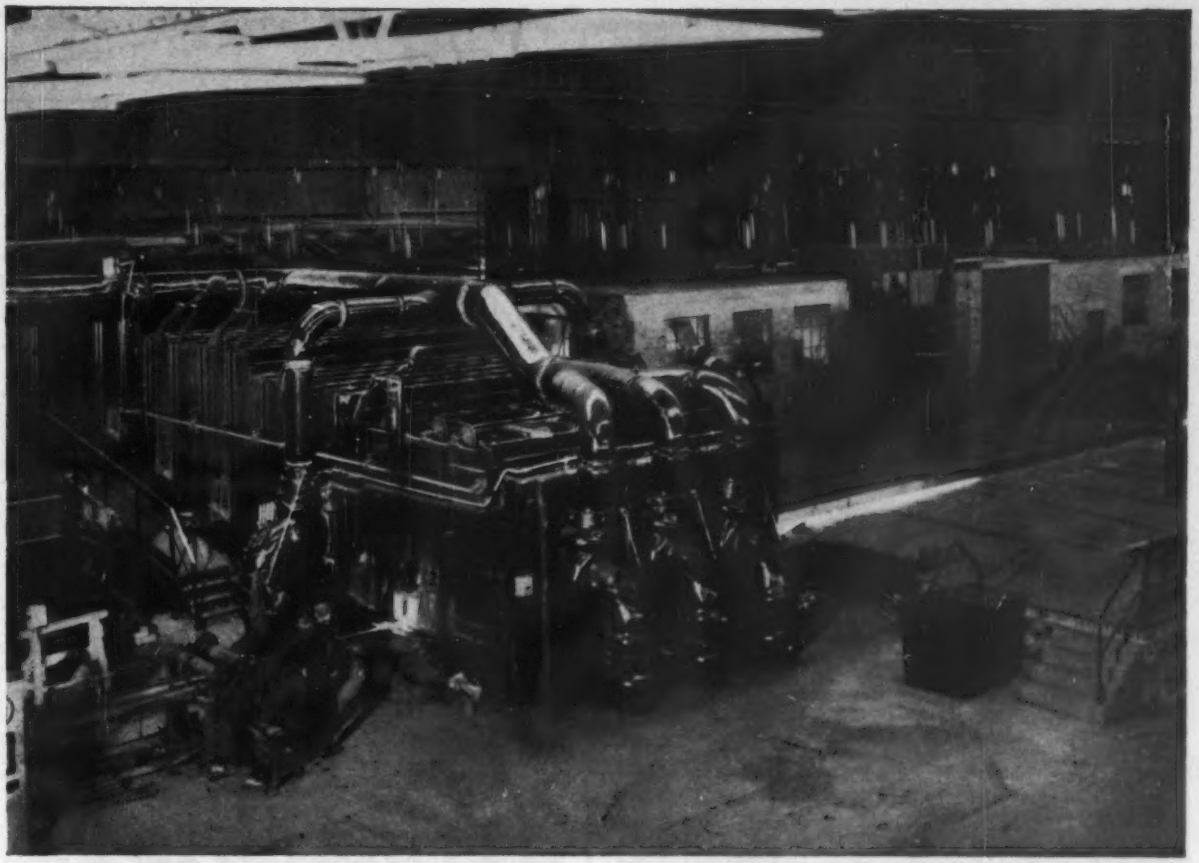

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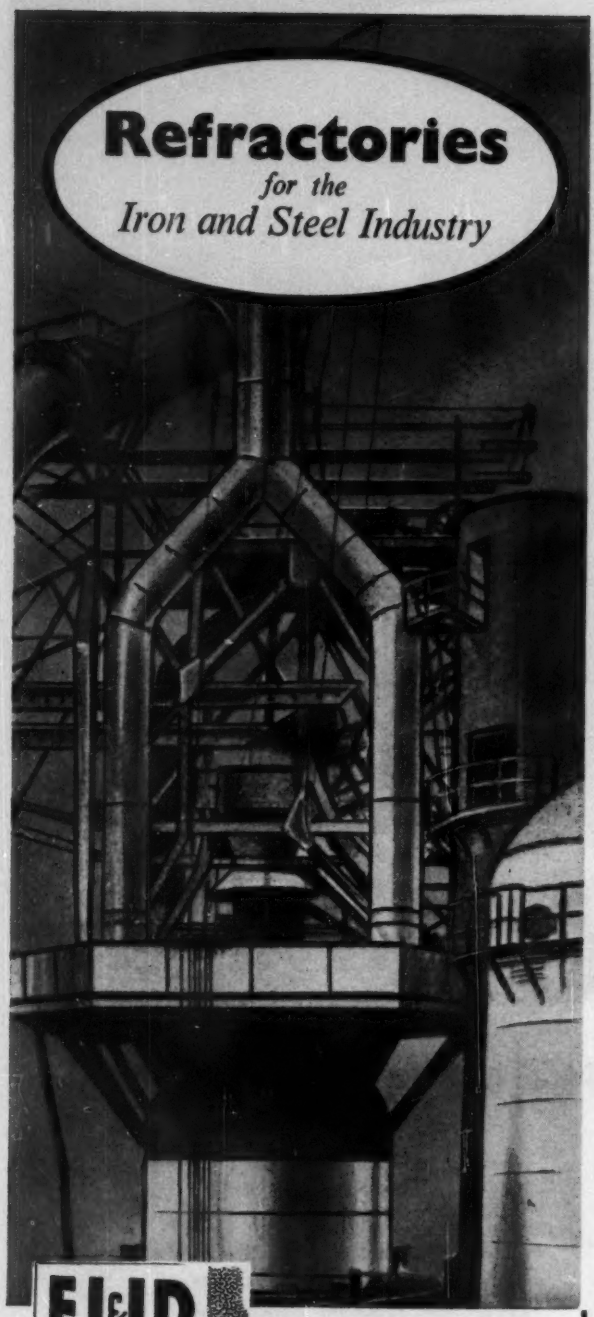

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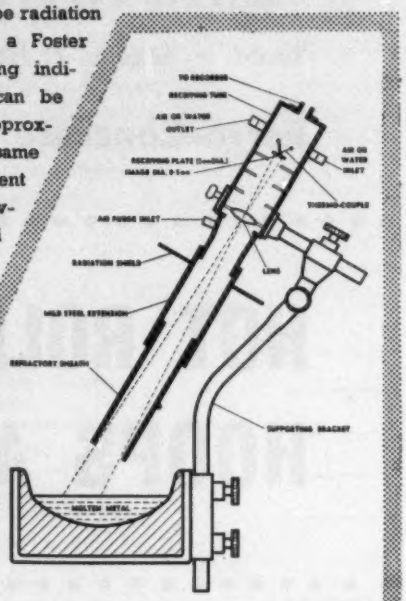

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COMBUSTION AND HEAT TRANSFER IN AN OPEN-HEARTH FURNACE

A RECENT addition to the Special Report series of the Institute is entitled "Combustion and Heat Transfer in an Open-Hearth Furnace," by S. W. Pearson, M. W. Thring, and J. H. Chesters. This Report describes a large-scale trial carried out on a Templeborough furnace with a team consisting of groups from Messrs. Steel, Peech and Tozer, the Research and Development Department of the United Steel Companies Ltd., the University of Sheffield, and the British Iron and Steel Research Association.

The previous Templeborough trials, reported in Special Report No. 37 (1946), emphasized the necessity for aerodynamic studies, continuous roof-temperature measurement, and the maintenance of the highest practicable furnace pressure. The shift from producer gas to oil firing in the last ten years has added new objectives, e.g. the determination of optimum nozzle size, steam/oil ratio, and burner direction. The work of the International Flame Radiation Committee at Ijmuiden has given preliminary answers to some of the questions, whilst the theory of heat transfer initially expounded in Special Report No. 37 has been developed to a point where calculated melting times and fuel consumptions are of the same order as those found in practice. The main purpose of the present trial was to measure as many factors as possible, leaving only one free parameter in each verifiable part of the calculation; this could then be determined from the observed result and the value thus obtained used with some confidence in future calculations. A subsidiary objective was the comparison of flow pattern and mixing in model and furnace.

The Report, No. 59 in the series, is fully illustrated with diagrams and photographs and is bound in cloth with stiff board covers. Copies may be obtained on application to the Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, price 37*s.* 6*d.* (Members 25*s.*).

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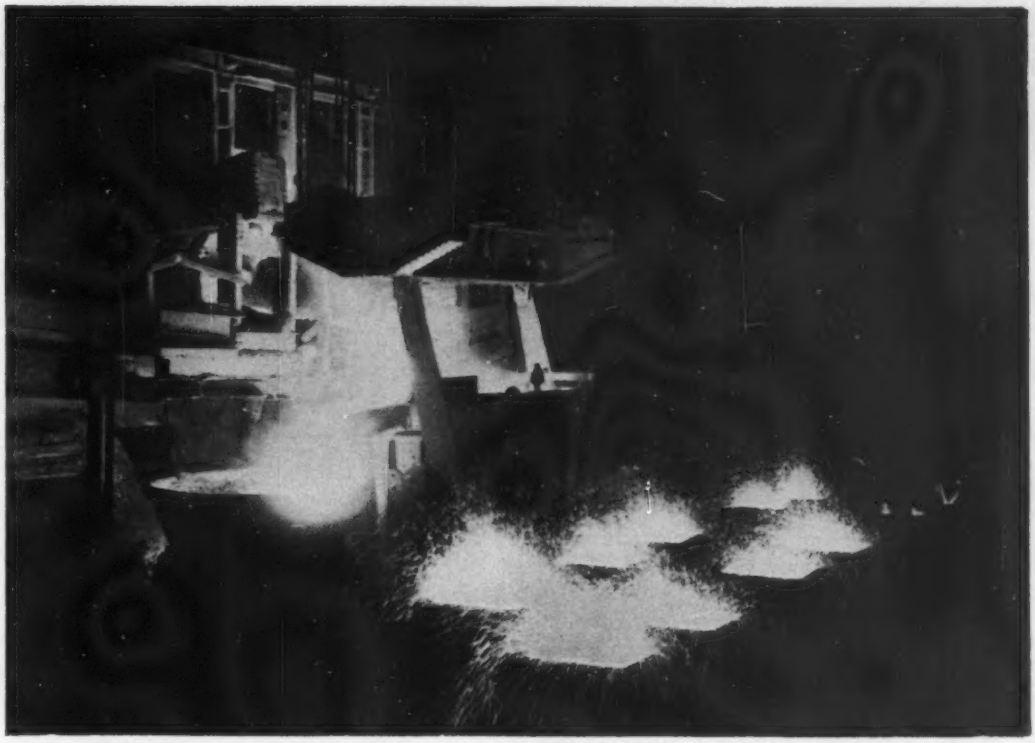

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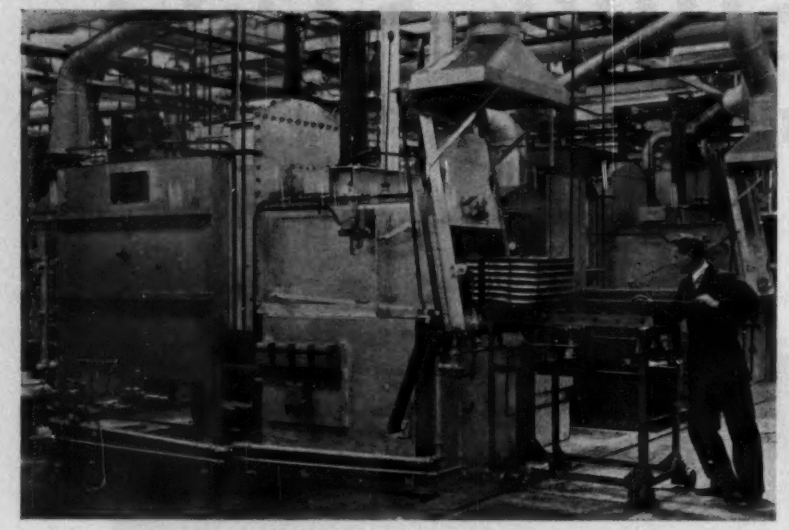

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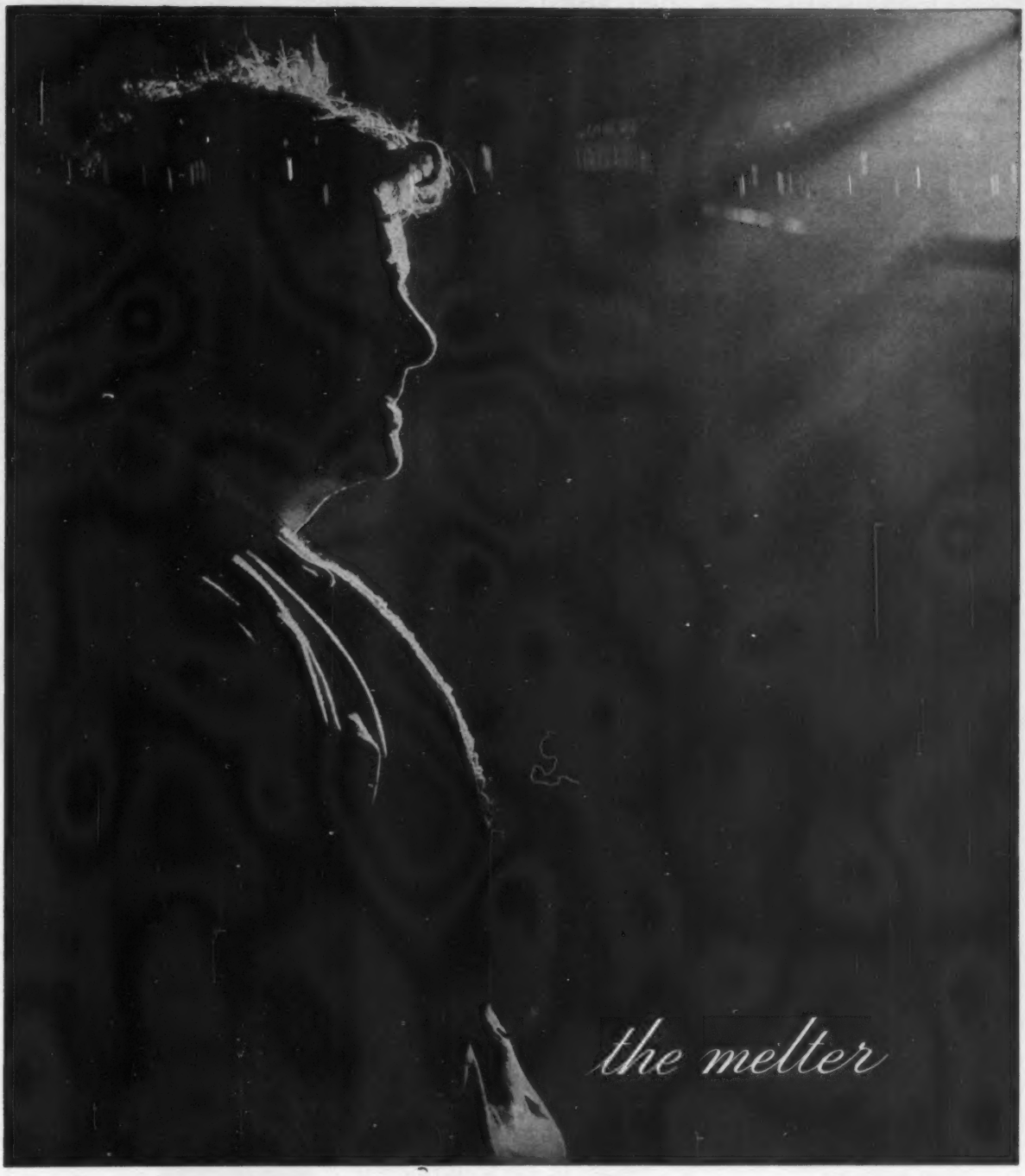

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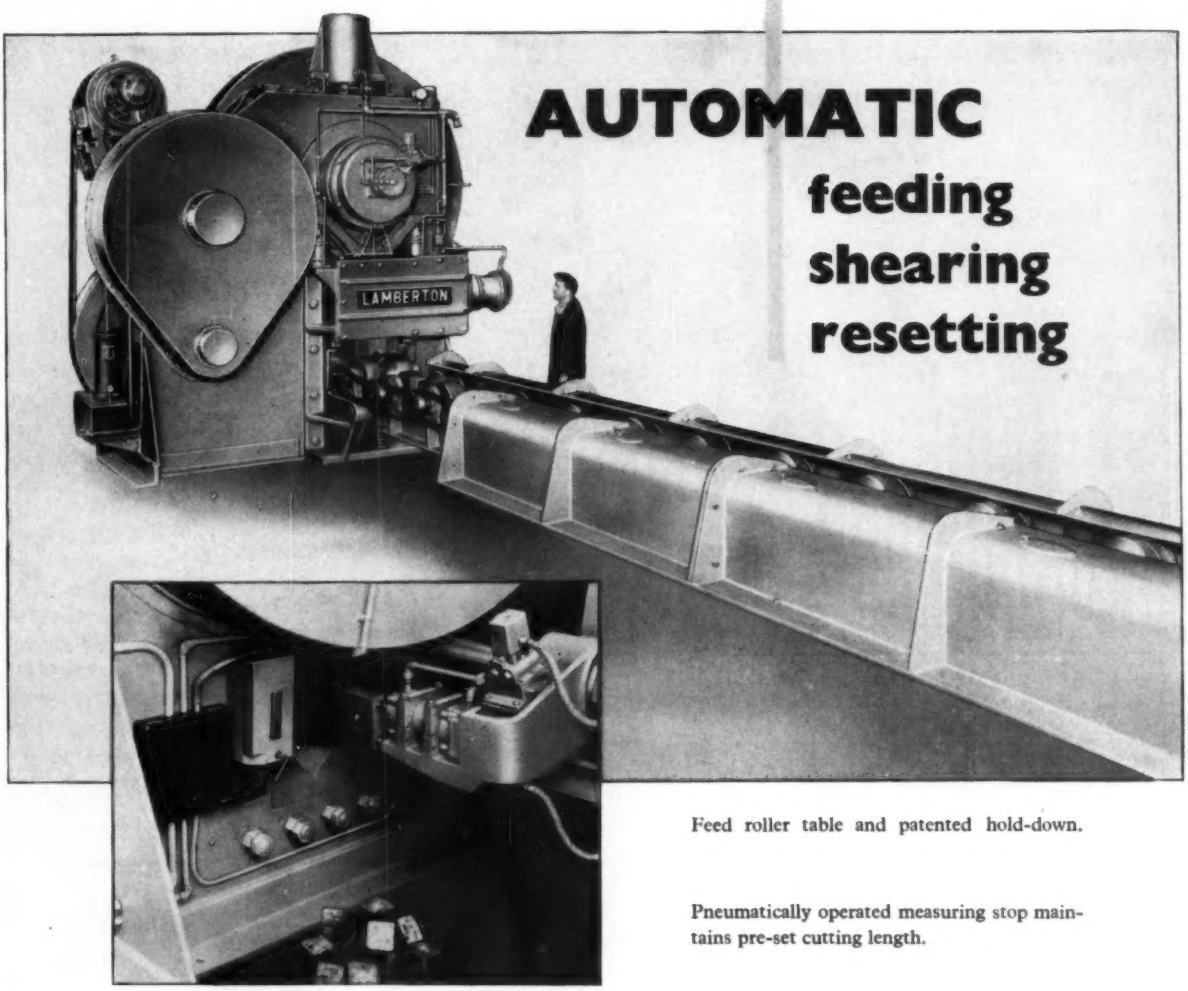

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